

GLOBAL CHANGE—AN OCEAN PERSPECTIVE

HEARING
BEFORE THE
NATIONAL OCEAN POLICY STUDY
OF THE
COMMITTEE ON COMMERCE,
SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE
ONE HUNDRED FIRST CONGRESS
FIRST SESSION
ON
GLOBAL CHANGE—AN OCEAN PERSPECTIVE

APRIL 11, 1989

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GLOBAL CHANGE—AN OCEAN PERSPECTIVE

TUESDAY, APRIL 11, 1989

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
NATIONAL OCEAN POLICY STUDY,
Washington, DC.

The subcommittee met at 2:00 p.m. in room SR-253, Russell Senate Office Building, Hon. John F. Kerry [vice chairman of the Study] presiding.

Staff members assigned to this hearing: Penny Dalton; Mike Nussman, professional staff members; and Bob Eisenbud, minority professional staff member.

OPENING STATEMENT BY SENATOR KERRY

Senator KERRY. The hearing will come to order. Good afternoon and welcome to this afternoon's hearing of the full committee and the National Ocean Policy Study on the role of oceans in global climate change.

This is a subject that has come up several times in the course of full committee hearings. It also came up in the hearings that Senator Gore has had on the global change issue.

We are particularly interested in pursuing the level of our knowledge today and the directions that we need to move in with respect to understanding oceans and their effect on, and participation in this entire process.

Obviously, last year's record heat across the country, the devastating drought that continues to be a problem in the Northeast and particularly in my home state of Massachusetts, as well as the recent oil spill in Alaska, all have served to raise America's consciousness about changes within our climatic system and about general threats to the environment.

We are not even certain about the causes of much of this change and much of it we are certain about. Some changes appear to be human-induced and we have come to the conclusion that man's actions are straining our resources.

Three weeks ago this was brought home to us in devastating form through the Alaskan oil spill. I am told that every year other oil spills, plus the normal use of tankers in our oceans, are putting some ten times the level of the Valdez oil spill into our oceans, so we obviously have some serious questions to ask about the impact.

The perception has grown that we are on a collision course with our own activities. At this time, those of us who are in public policy positions are trying to determine what can best be done and

where to place our priorities and expenditures. We are searching for scientific guidance and for input.

It is hard to decide what to do unless you understand completely what is being done to our planet. At this point in time most of the research emphasis appears to have been on the atmosphere. Clearly the oceans act as a major partner in creating climate patterns on this planet, for example the El Nino or La Nina effects of hot or cold inputs respectively in the Pacific Ocean. I understand that scientists now by and large believe last year's drought was caused by the jet stream transition which in turn came through a change in the Pacific Ocean heating. As a result, it is clear that variations in Pacific Ocean conditions can cause water shortages in the Northeast of this country. Similarly, across the ocean, other countries can be affected by what is happening.

The bottom line is clear. We need to know more about the relationships between phytoplankton production and ozone depletion, among the various ecosystems of the ocean, as well as the effect of tar gathering on the ocean's bottom and the various other toxic spills that are occurring into our water bodies.

We had testimony last year at a hearing that I chaired regarding acid rain in which it became clear that nitrate overloading can cause algae blooms. Other adverse effects could conceivably be caused by similar overloading of other kinds of nutrients or chemicals into the water bodies. We do not know the answers to that.

So, these are a critical set of questions that we need to ask as we proceed. We also know that the ocean is a giant reservoir for approximately 45 percent of the carbon dioxide that is emitted through the burning of fossil fuels. Obviously there are serious questions about the relationship between the oceans' capacity to continue to absorb carbon dioxide or conceivably reach the limit of its capacity to do so and the whole issue of global warming. That is an effect that we need to understand and study further.

So, this hearing's purpose is exploratory, informational. We want to hear from a set of experts about what they believe are the current operational guidelines within which we are functioning, and to try to set a clearer agenda in understanding how NOAA and other agencies can help to chart a course for the future. It obviously is important I think to do so rapidly because most people believe that the clock is ticking on this issue.

So, I am delighted to welcome a number of expert witnesses. With us are the Assistant Secretary of Commerce, Kent Burton; Dr. John Wallace, the Director of the Joint Institute for Studies of the Atmosphere and Ocean; Dr. Peter Brewer from the Woods Hole Oceanographic Institute in Massachusetts; Dr. Hugh Ducklow, the Associate Professor of the University of Maryland, Horn Point Environmental Laboratory; and Dr. Francis Bretherton, Director of the Space Science and Engineering Center of the University of Wisconsin.

I would also like to turn to my colleagues now. I am afraid I did not see your order of appearance. Why do we not begin with Senator Kasten. Do you have an opening statement?

OPENING STATEMENT BY SENATOR KASTEN

Senator KASTEN. Mr. Chairman, thank you very much. I would like to make a brief opening statement because this afternoon we are going to be confirming Susan Engeleiter to be Chairman of the Small Business Administration. I am not going to be able to be here for this hearing, but I would like to particularly welcome Dr. Francis Bretherton, who is the Director of the Space Science and Engineering Center of the University of Wisconsin.

Dr. Bretherton is perhaps the world's foremost authority on projections of atmospheric changes associated with man's actions, so it is a special pleasure to have him as well as the other eminent scientists here today.

I think, Mr. Chairman, it is very timely that we are holding this hearing today to review the implications of climate change for our oceans and also for our Great Lakes.

There is considerable debate about the capacity of the oceans to moderate the effects of carbon loading in the atmosphere. I hope that today we can identify some of the likely biological and physical changes in large bodies of water that would impact on global warming.

In particular, I am interested in learning more about the function of these large masses and stabilizing temperature shifts, changes in biological functions within the oceans and Great Lakes that could moderate or possibly exacerbate the temperature change and carbon loading and the likely impacts of this phenomenon not only on the oceans, but the Great Lakes.

Senator KERRY. Senator Kasten, thank you.

Senator Pressler.

OPENING STATEMENT BY SENATOR PRESSLER

Senator PRESSLER. Mr. Chairman, this is my second hearing today on global warming issues. This morning we were talking about NASA's role in getting information and also the role of the EROS Data Center near Sioux Falls in archiving those pictures be they from Landsat or future satellites.

We are entering into a very exciting period trying to study what is going on in our environment and in the warming of the earth, not only from the oceans but also from the forests and from the pollution that is caused by man.

This morning we were talking about NASA's role in the space station and some of the studies of the earth and its oceans, getting pictures and information, and archiving, presenting, and using that information. This is an important part of that process.

Mr. Chairman, thank you for scheduling today's hearing on this very important issue. Global warming is a phenomenon that is happening now, in the opinion of most experts, and it will continue. The only questions are how fast that process will occur, how severe it will become, and what can and should we do about it.

The role of the oceans in determining the global climate is immense, perhaps greater than any other earthly factor, including man's input through fossil fuel burning, CFC production, and so on. Therefore, it is essential to understand this role. I hope this hearing will enable me to better understand what we currently know

about the role of the oceans and what we are doing to understand it better.

The leadership of this committee has demonstrated its commitment to global change research and action. We have held hearings in the full committee, the Science Subcommittee, and now the National Ocean Policy Study. Bills have been introduced, including S. 169, the National Global Change Research Act, introduced by Senator Hollings. I am an original cosponsor of that legislation, which would establish an overall framework for interagency cooperation in global change research.

I want to reiterate to the witnesses here that this is not a passing interest on the part of the members of this committee. It is not a passing interest on the part of the American people. This issue will not go away. I want to know what is currently being done through government and private research. More importantly, I would like to hear from you what Congress can do to help accelerate action on this problem.

Thank you, Mr. Chairman.

Senator KERRY. Thank you very much, Senator Pressler.

Senator Burns.

Senator BURNS. Thank you, Mr. Chairman. I have no statement to make at this time. I guess I am in the same car as Senator Pressler and Senator Kasten. I just dropped by to sort of listen in today, and I appreciate this opportunity because I have some serious concerns about this matter. We have to go and confirm Susan Engleleiter to the SBA, so thank you very much, but I have no statement though I will ask some questions later on.

Senator KERRY. Thank you very much.

I have a statement that the Chairman, Senator Hollings, would like to have included in the record.

[The statement follows:]

OPENING STATEMENT BY THE CHAIRMAN

Today's hearing brings two of my longstanding interests—the oceans and the National Oceanic and Atmospheric Administration—together in the context of growing concern about global environmental change. Looking back over the past two decades, I can think of no time since we created NOAA in 1970, that this relationship has been thoughtfully reviewed. Nineteen years is a long time—particularly for politicians. And our attention and consideration are long overdue.

As most of you know, I was deeply involved in the events which led to establishment of NOAA almost two decades ago. Many of our goals and objectives which we stated at that time may be more critical today than they were when the agency was formed. Recalling my words at the time:

"The new NOAA should encourage, develop, and sustain a national program in the marine and atmospheric environments, conducted so as to contribute to the following objectives:

"1. The expansion of human knowledge of the marine and atmospheric environments, and

"2. The advancement of capability to observe and predict environmental changes, . . . in order to enhance the safety and welfare of the public and to permit more efficient use of the oceans and atmosphere."

The statement goes on to outline several additional goals, but these two seem particularly relevant to our discussion today.

I appreciate the efforts of Dr. Eddy, Dr. Bretherton and the other members of the NOAA Panel on Climate and Global Change and I agree with their assessment. Through its missions and responsibilities, NOAA has an opportunity to play a key role in global change. I look forward to today's testimony to provide the direction we need to prevent that opportunity from passing us by.

Senator KERRY. Mr. Burton, we are delighted to have you here. Thank you for coming, and I look forward to your testimony. You are accompanied by an army of cohorts. Maybe you want to tell us who is here with you.

STATEMENT OF R. KENT BURTON, ASSISTANT SECRETARY FOR OCEANS AND ATMOSPHERE, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, DEPARTMENT OF COMMERCE; ACCOMPANIED BY DR. GLENN FLITTNER, ACTING DIRECTOR OF THE OFFICE OF RESEARCH AND ENVIRONMENTAL INFORMATION FOR THE NATIONAL MARINE FISHERIES SERVICE; DR. ALAN THOMAS, ACTING ASSISTANT ADMINISTRATOR FOR OCEANIC AND ATMOSPHERIC RESEARCH; AND DR. THOMAS PYKE, ASSISTANT ADMINISTRATOR, NATIONAL ENVIRONMENTAL SATELLITE, DATA, AND INFORMATION SERVICE

Mr. BURTON. Let me introduce them. To my left is Dr. Tom Pyke, Assistant Administrator for the National Environmental Satellite, Data, and Information Service. To my right is Dr. Alan Thomas, Acting Assistant Administrator for Oceanic and Atmospheric Research, and to his right is Dr. Glenn Flittner, Acting Director of the Office of Research and Environmental Information for the National Marine Fisheries Service.

I am delighted to have these gentlemen with me. They represent three of the five line offices which have a significant role in our global change initiative, and anticipating issues that may arise in their areas of responsibility, they are here to respond to questions.

I appreciate the opportunity to be here before you today, Mr. Chairman. It will be a delight to discuss NOAA's programs on global change, of the increasing significance of determining the ocean's role, as you point out, in the prediction of global change and the assessment and stewardship of our coastal ocean environment and resources.

Senator KERRY. Let me just interrupt you very quickly to say that because of the number of people who are going to testify, we want to try to keep this moving, and I am also on a slightly tight schedule. So, if you could summarize we would appreciate it.

Mr. BURTON. I will seek to summarize indeed.

Let me just touch on a few highlights of the statement. We have prepared a full statement for the record, Senator.

NOAA's historic monitoring and prediction responsibilities lead naturally into an operational long-term view of the ocean, one which is critical for the development, we believe, of a national program in global change.

When NOAA was first organized in 1970 to accompany Reorganization Plan Number 4, President Nixon said the following which may be of interest to the committee, and I quote here—this is the President:

The oceans and atmosphere are interacting parts of the total environmental system upon which we depend, not only for the quality of our lives, but for life itself.

The President went on:

We face immediate and compelling needs for better understanding of the environment, an understanding which will enable us more effectively to monitor and pre-

dict its actions, and ultimately, perhaps to exercise some degree of control over them.

I think that epitomizes well the mission that NOAA has when it comes to global change, which is so important to us now. The climate and global change program is focused as a result around four program elements: Long-term Observations, Climate Process Studies, Climate Diagnostics and Prediction, and Climate Data Services.

I am just going to touch briefly on each of them. The fact that the upper three meters of the ocean alone can hold as much heat as the entire atmosphere makes it clear that understanding climate variability extending over a number of years must involve the ocean in an important way.

Thus, in order to predict the evolution of climate, we must have in place an integrated observing system to specify the state of the ocean, and models capable of assimilating these ocean observations together with other earth system data to predict the future state of the coupled ocean-atmosphere system.

NOAA maintains operational models and long-term ocean observation systems used in the prediction of climate. In the tropical Pacific a large scale network for upper ocean thermal structure, sea level, and surface winds monitors the evolution of El Nino events that you mentioned earlier.

Our knowledge of ocean circulation is far less advanced than our understanding of atmospheric circulation, and that disparity is something that we need to address and which our program intends to address. For this reason, NOAA and other Federal agencies support and participate in the World Ocean Circulation Experiment which is known in the community as WOCE. This is a multi-year, international effort to better define the circulation of the global ocean.

Another element is the biogenic chemical cycling of climatically important gases. It is estimated that 40 percent of the annual release of fossil fuel CO_2 is absorbed by the ocean. You pointed to this figure earlier, Mr. Chairman. However, while it is recognized that the world's oceans regulate the degree to which CO_2 has increased in the atmosphere, there are no consistent time series measurements of oceanic CO_2 to parallel the atmospheric record.

In coordination with the Joint Global Ocean Flux Study, NOAA and other Federal agencies are developing plans to undertake the long-term, large-scale measurements of ocean carbon necessary for modeling its interaction with the atmosphere.

Recent research has also indicated that the ocean may influence climate through the formation of clouds. A major source of cloud condensation nuclei over the ocean is a sulfur compound produced by phytoplankton which forms an aerosol in the atmosphere.

Developing a climate prediction capability will also, we believe, require improving our ability to model the ocean and atmosphere and assimilate data from an ocean monitoring system. NOAA, through the Geophysical Fluid Dynamics Laboratory at Princeton, and the National Meteorological Center, pursues a vigorous modeling strategy developing oceanic, atmospheric, and coupled ocean-atmosphere models.

Let me jump to inter-annual climate variability. One of the principal reasons for optimism in the pursuit of long-term climate pre-

diction is the progress which has been made in understanding the role of the equatorial ocean in inter-annual climate change as a result of the TOGA [Tropical Ocean-Global Atmosphere] program. We now have in place an operational ocean model which incorporates ocean data on a regular basis and can simulate many aspects of the evolution of El Nino events.

TOGA research has provided insights into climate variability beyond the tropics. Recent findings suggest that the cold water in the equatorial Pacific following the 1987 El Nino played a prominent role in the North American drought of 1988, which we also spoke of. Diagnostic studies suggest that the ridge of high pressure over the American Midwest was linked by an atmospheric wave train to the tropical Pacific, somewhat like a boulder in a river causing ripples downstream.

Unraveling the progression of such climatic events is one of the keys to development of predictive skill. That predictive skill is, we believe, the benchmark of what NOAA is all about, the mission being prediction of climatic events not only day-to-day, which is the mission of the National Weather Service, but hopefully on an inter-annual basis which is the mission of our initiative.

In regard to climate data and information, archiving data is an absolute key part of the mission which Senator Pressler mentioned earlier. Much of our current knowledge about climate change and climate variations has been gleaned from oceanic data. NOAA has taken a first step toward producing a consistent data base of marine observations through development of COADS, which is the Comprehensive Ocean-Atmosphere Data Set. This will ensure that data from new NOAA observing programs will be consistent with and can be integrated with the historical data base.

NOAA is committed to the provision of bias-free data to those in the scientific community involved with the detection of climate change and documentation of the natural variability of climate. We are actively supporting the newly-formed Interagency Working Group on Data Management for Global Change.

Finally, Mr. Chairman, in response to your letter of invitation, I would like to address briefly the recent report of the NOAA Panel on Climate and Global Change. The report, which is entitled "The U.S. Global Change Program, The Vision: A Rededication of NOAA", represented an important collaboration with the U.S. scientific community in the evolution of NOAA's Climate and Global Change Program.

The report reaffirms the Administration's position that NOAA will make an important contribution to national and international global change efforts.

The report raises a number of important points concerning the nature of NOAA's global change responsibilities, and as a result, I believe, merits careful consideration and discussion which we have already undertaken. I view the document as an important first step in a continuing dialogue on this subject, and look forward to meeting with the members of the panel in the very near future to discuss the report and its specific implications for NOAA.

In conclusion, let me say we believe NOAA's ocean programs are a part of the foundation for a climate predictive capability.

One of the principal objectives of the U.S. Global Change Research Program, predictive capability, is something that characterizes in particular the mission of NOAA through its participation in the Interagency Committee on Earth Science.

NOAA will continue to participate in the development and implementation of an effective and integrated program to address global environmental change.

That concludes my presentation. As I mentioned, there are more comments we will be making for the record, and we will be happy to try and answer questions, Mr. Chairman.

[The statement follows:]

STATEMENT OF

B. KENT BURTON
ASSISTANT SECRETARY FOR OCEANS AND ATMOSPHERE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
UNITED STATES DEPARTMENT OF COMMERCE

BEFORE THE

COMMITTEE ON COMMERCE, SCIENCE AND TRANSPORTATION
AND
NATIONAL OCEAN POLICY STUDY
UNITED STATES SENATE

APRIL 11, 1989

Mr. Chairman and Members of the Committee:

My name is Kent Burton. I am the Assistant Secretary for Oceans and Atmosphere and the Deputy Administrator of the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce. Thank you for the opportunity to discuss NOAA's programs in Global Change and the increasing significance of determining the ocean's role in the prediction of global change and the assessment and stewardship of our coastal ocean environment and resources. NOAA's Climate and Global Change Program has recognized the importance of the ocean to global change and has devoted a large part of the program to oceanic issues. The oceanic portions of Climate and Global Change will help the program attain its objective of achieving reliable assessments and quantitative predictions of changing global climate.

NOAA's historic monitoring and prediction responsibilities lead naturally into an operational, long-term view of the ocean, one which is critical to the development of a national program in global change research. This is also consistent with NOAA's role as an environmental service, described by Richard Nixon in a Statement to the Congress accompanying Reorganization Plan Number 4 of 1970, which created NOAA:

"...The oceans and atmosphere are interacting parts of the total environmental system upon which we depend not only for the quality of our lives, but for life itself... We face immediate and compelling needs for a better understanding of the environment - an understanding which will enable us more effectively to monitor and predict its actions, and ultimately, perhaps to exercise some degree of control over them."

NOAA's Climate and Global Change Program is managed in such a way as to emphasize cooperative efforts throughout NOAA, starting with myself and the Assistant Administrators. The central focus of the Program is NOAA's Office of Global Programs, responsible for coordinating the activities. Finally, an external panel of scientific advisors provides scientific input regarding the direction for the program. NOAA actively coordinates with other Federal agencies through the Committee on Earth Sciences and the Office of Management and Budget.

The Climate and Global Change Program is focused around four program elements: Long-term Observations, Climate Process Studies, Climate Diagnostics and Prediction, and Climate Data Services. Each of these elements incorporates an oceanic aspect. One of the major areas limiting our ability to predict global climate change is the role of the ocean in the exchange of heat, water and trace gases with the atmosphere. NOAA's ocean programs are designed to further our capacity to document and predict climate change and to project the impacts of this change on our ocean resources. Many of these oceanic programs are part of NOAA's ongoing base activities, but the majority of the proposed new efforts are being advanced as part of the Climate and Global Change Program.

Ocean Circulation

The fact that the upper three meters of the ocean alone can hold as much heat as the entire atmosphere, makes it clear that understanding climate variability extending over a number of years must involve the ocean in an important way. Thus in order to predict the evolution of climate, we must have in place an integrated observing system to specify the state of the ocean and models capable of assimilating these ocean observations together with other Earth system data to predict the future state of the coupled ocean-atmosphere system. In many ways we are in an analogous situation to that of numerical weather prediction in the 1950's, when computer models and the weather observing

network were in their early stages. NOAA maintains operational models and long-term ocean observation systems used in the prediction of climate.

The rudiments of such an ocean observing system exist now in the tropical Pacific, where a large-scale network for upper ocean thermal structure, sea level and surface winds monitors the evolution of El Nino-type events. In addition, environmental satellites operated by NOAA play a key role in monitoring the global sea surface temperature, cloud cover, solar and longwave radiation, and rainfall over the oceans. We foresee significant expansion of our ocean observing network as part of the climate global program to encompass the entire Pacific Basin out of the tropics as guided by the informational needs of emerging ocean models. Such models have demonstrated the ability to assimilate these large volumes of ocean data in the most effective manner possible. A full scale ocean-basin network would also entail maintaining global observations of sea surface temperature, a fundamental air-sea interaction parameter; geochemical tracers, a measure of long-term ocean circulation; and sea ice, a sensitive indicator of climate change and an important factor governing the heat balance of the high latitude ocean-atmosphere system.

Sea level measurements have an important place in the ocean observing system, since the time series of rising sea level is one of the most prominent data sets which have alerted scientists and the public to global change. NOAA will continue

installation of a global network to provide accurate measurements of absolute sea level. This baseline will allow the determination of long-term sea level rise without the bias caused by independent land motions. On global scales, NOAA's use of the Navy GEOSAT satellite altimeter has resulted in the operational production of monthly maps of relative sea level over entire ocean basins, and this will be continued under the Climate and Global Change Program.

Predictive modeling of the coupled ocean-atmosphere system clearly requires a stronger basic understanding of the way heat and trace gases are exchanged across the ocean-atmosphere boundary. Our knowledge of ocean circulation is far less advanced than our understanding of the atmospheric circulation. For this reason NOAA and other Federal agencies support and participant in the World Ocean Circulation Experiment (WOCE), a multi-year international effort to better define the circulation of the global ocean. At the same time, research results from the coupled ocean-atmosphere models and the study of past climates suggest that there are certain areas of the ocean such as the North Atlantic, which exert a disproportionate influence over long-term climate change. On-going research in such areas may lead to notable advances in understanding, just as TOGA (Tropical Ocean-Global Atmosphere) investigations in the tropical Pacific have broadened our knowledge of El Nino phenomena.

Biogeochemical Cycling and Climatically Important Gases

Our lack of knowledge of the ocean's physical and biogeochemical control over levels of atmospheric trace gases limits our ability to predict future climate. It is estimated that 40% of the annual release of fossil fuel CO_2 is absorbed by the oceans. However, while it is recognized that the world's oceans regulate the degree to which CO_2 has increased in the atmosphere, there are no consistent time series measurements of oceanic CO_2 to parallel the atmospheric record. In coordination with other large international programs such as WOCE and the Joint Global Ocean Flux Study, NOAA and other Federal agencies are developing plans to undertake the long-term, large-scale measurements of ocean carbon necessary for modeling its interaction with the atmosphere. Only an understanding of the important pathways, fluxes and storage of carbon in the ocean will allow a reliable prediction of the long-term climatic impact of fossil fuel combustion and/or mitigation efforts regarding such combustion.

Recent research has also indicated that the ocean may influence climate through the formation of clouds. The major source of cloud condensation nuclei over the ocean is a sulfur compound produced by phytoplankton which forms an aerosol in the atmosphere. Because the reflectance of clouds (and thus the Earth's radiation budget) is sensitive to the density of condensation nuclei, biological regulation of climate is

possible through the effects of temperature and sunlight on phytoplankton production of these cloud condensation nuclei.

Oceanic and Atmospheric Modeling

Developing a climate prediction capability will require improving our ability to model the ocean and atmosphere and assimilate data from an ocean monitoring system. NOAA, through the Geophysical Fluid Dynamics Laboratory (GFDL) at Princeton, NJ, and the National Meteorological Center (NMC), pursues a vigorous modeling strategy developing oceanic, atmospheric, and coupled ocean-atmosphere models. I have mentioned examples of the close interaction among ocean monitoring, research, and modeling which NOAA brings to the Climate and Global Change Program. To strengthen the modeling and prediction capability, we are requesting funding in FY90 to obtain seventh generation supercomputers for ocean modeling research and other purposes at GFDL and for operational uses at NMC.

Climate Change and Fisheries Productivity

In addition to examining the biological influences on climate, we know that long-term changes in the ocean environment can affect the living marine resources over which NOAA has stewardship. Our research indicates that fisheries cannot be effectively managed on the basis of catch and effort statistics alone, since much variability in fish stocks is caused by

climate-driven ocean variability. Thus one of the major users of climate data and information will be the global fisheries management community.

Interannual Climate Variability

One of the principal reasons for optimism in the pursuit of long-term climate prediction is the progress which has been made in understanding the role of the equatorial ocean in interannual climate change as a result of the TOGA program. We now have in place an operational ocean model which incorporates ocean data on a regular basis and can simulate many aspects of the evolution of El Nino events. From this work, it was found that the primary weakness in our modeling ability for the tropical surface ocean was the lack of adequate wind information. A substantial increase in the number of our surface wind observational sites is being considered to address this need.

TOGA research has also shown that one of the dominant features of the Earth's climate system on interannual time scales is the formation and dissipation of a huge pool of warm water in the western Pacific, a precursor to the El Nino events. A principal focus of TOGA in the early 1990's will be the investigation of the processes by which this pool is formed.

TOGA research has provided insights into climate variability beyond the tropics. Recent findings suggest that the cold water in the equatorial Pacific following the 1987 El Nino played a prominent role in the North American drought of 1988. Diagnostic

studies suggest that the ridge of high pressure over the American Midwest was linked by an atmospheric wave train to the tropical Pacific, somewhat like a boulder in a river causing ripples downstream. Unraveling the progression of such climatic events is one of the keys to development of predictive skill.

Climate Data and Information

One of NOAA's global change responsibilities is the compilation and maintenance of consistent high-quality data bases of marine observations which have been collected across the globe since 1860. Much of our current knowledge about climate change and climate variations has been gleaned from oceanic data. NOAA has taken a first step toward producing a consistent data base of marine observations through development of the COADS (Comprehensive Ocean-Atmosphere Data Set) and will ensure that data from new NOAA observing programs will be consistent with and can be integrated with the historical data base. NOAA is committed to the provision of bias-free data to those in the scientific community involved with the detection of climate change and documentation of the natural variability of climate. We recognize that data and information are the keys to unlocking the global change problem, and we are actively supporting the newly-formed Interagency Working Group on Data Management for Global Change. The goal is a virtual national data and information system for global change research by 1995 that is consistent across agencies, and involves and supports the university and other user communities.

The NOAA Panel Report

Finally, in response to your letter, I'd like to address the recent Report of the NOAA Panel on Climate and Global Change. The Report, entitled THE U.S. GLOBAL CHANGE PROGRAM, THE VISION: A REDEDICATION OF NOAA, represented an important collaboration with the U.S. scientific community in the evolution of NOAA's Climate and Global Change Program.

The report reaffirms the Administration's position that NOAA will make an important contribution to national and international global change efforts. The panel is in agreement with the Committee on Earth Sciences, of which NOAA is an active participant, regarding NOAA's role in global change as being long-term monitoring, short - and long-term prediction and data information services. I hope that this Congress will support the Administration's request to more than double the NOAA's global change program in 1990, in order that NOAA can actively pursue its vital role in the development of an integrated program to address global environmental change.

The Report raises a number of important points concerning the nature of NOAA's global change responsibilities and, therefore, merits careful consideration and discussion. I view the document as an important first step in a continuing dialogue on this subject and look forward to meeting with members of the Panel soon to discuss the Report and its specific implications for NOAA.

In conclusion, we believe that NOAA's ocean programs are part of the foundation for a climate predictive capability, one of the principal objectives of the U.S. Global Change Research Program. Through its participation in the interagency Committee on Earth Science, NOAA will continue to participate in the development and implementation of an effective and integrated program to address global environmental change.

Senator KERRY. Thank you very much. Let me just say that your full testimony will be placed in the record.

Senator Gorton, do you have any opening comment you wish to make?

Senator GORTON. No, I do not, Mr. Chairman. Thank you.

Senator KERRY. Very well.

In your testimony and in your opening here you cite the President's 1970 words about the mission of NOAA. In laymen's terms measuring it against what we now see or think we see as the problem, how would you evaluate the degree to which NOAA has or has not really met the vision with which it was created? Where would you say you are today, a candid assessment?

Mr. BURTON. Sure. I would give us something like a B minus, C plus, slightly above pass. We can do a lot better. I believe NOAA's science has in the community a good reputation.

There are those who have been concerned with the level to which the administration has supported NOAA's mission in the past several years, but one area in which I do believe we have generally distinguished ourselves is atmospheric science.

I think we have come to have a reputation as good honest brokers of science in this area, a recognition that has been given. Notwithstanding the comment I just made, however, is the fact that the Administration has stepped up to this. They recognize the importance of the global change initiative.

NOAA, I believe, was at the starting gate before anyone else in terms of recognizing the attention that the subject needed. We, along with the United States Geological Service and the National Science Foundation, were the original members of the Committee on Earth Sciences, which NOAA originally chaired a couple of years back; all that represents, I think, an excellent recognition by NOAA, and now by the Administration, that this is a terribly important area and one in which NOAA is growing into very well.

The 1990 budget request, I think, is a further reflection of the importance we are attaching to this. I think in the months and years to come NOAA is going to be very much a player in this game, as we are already, but a more active participant as we meet the challenge that the global change problem represents.

Senator KERRY. Would you say that the chain of command is clear enough with respect to NOAA's mission versus the other agencies that are also looking at this question of global warming?

Mr. BURTON. The chain of command coming from the Department to NOAA to the line offices, is that what you are referring to, Mr. Chairman?

Mr. KERRY. Well, you talked about the interagency planning group working well. Is it your sense that there really is full coordination now or that people are going off on their own tangents?

Mr. BURTON. I think there is good coordination. I think the core group on the Committee on Earth Sciences communicate regularly. There is an active working panel connected with that.

I believe we have a good understanding as is reflected by the appendix to the budget that came up this year. It is one of the first times that sort of an appendix accompanied the budget, recognizing again the Administration's commitment. But also I think it fairly represents the understanding on the part of the key players as to

what their mission is and also represents the coordination that went into creating that document. It is a fair reflection of a coordinated work product that is being strived for among the key agencies.

I think it is fair to say the coordination is well in place, and we are moving ahead in a smart fashion toward the goal.

Mr. KERRY. Can you give us a sense—and I do not know if this is possible, but on a scale of perhaps one to ten where would you say we are in our understanding of the atmospheric impact on global change?

Mr. BURTON. You ask for a numerical representation. I am going to defer to my atmospheric scientist to my right, Dr. Thomas. Maybe he can give a little more precise answer to that.

Dr. THOMAS. I am not sure that I can quite put it on a scale, but there are a number of things that we do know about how the atmosphere works, and I think you will be hearing testimony—

Senator KERRY. Well, I guess what I am really getting at—I do not want to talk around this—is that clearly there is a discrepancy between what we know about the atmosphere versus what we know about oceans, correct?

Dr. THOMAS. Okay, yes. In that regard our ability to, say, model the ocean is a number of years behind our ability to simulate the atmosphere.

We have been doing atmospheric modeling for 30 years now. Ocean modeling is of much more recent vintage.

Senator KERRY. Why is that? What is the explanation for that?

Dr. THOMAS. Well, the first driving factor for us, getting into atmospheric modeling, was forecasting the weather. That had a more immediate priority at the time. So, there was a lot of effort, both nationally and internationally, in advancing the science.

One of the first big international programs was the Global Atmospheric Research Program that started in the sixties and went through the decade of the seventies. That is a very valuable program. It is one that we as an agency feel very proud of our role within the Federal government and in the international community. So, I think the attention to weather and its effect drove the atmospheric sciences faster, say, than the ocean sciences.

Senator KERRY. Is it your sense, Secretary Burton, that NOAA currently has the resources necessary to complete its mission in terms of the current challenge of global change?

Mr. BURTON. I think the budget request for FY 1990 and what it represents in terms of filling our needs is a fair request. The resources that it would give us, I think, will move the state of the art forward. The plans we have for our role in understanding the ocean and the atmosphere as a body, I think, anticipate the receipt of resources that, yes, will permit us to fulfill our mission as a significant player among the other Federal agencies.

We are confident that it does its job, sir.

Senator KERRY. Well, that 1990 budget for global change research in the area of ecological systems apparently requests no NOAA funds. Now, your agency has primary responsibility for monitoring marine environment, but there is no funding for that research. How do you account for that? How can you possibly fulfill the mission if there is no money?

Mr. BURTON. Number one, it does not anticipate or measure what we are doing within the base to understand ecological systems. We think we are doing some systems already, contributing programs within NOAA already that are on the books that identify ecological systems and dynamic resources which are associated primarily with base programs.

Beyond that, with regard to our request, our decision was to seek for critical enhancement activities directly related to developing our operational capability for longer-term climate change as a first priority. We already have base resources that I think are in place. Beyond that we also have a Coastal Ocean Program initiative that contemplates the needs in the area of ecological systems which when combined with base resources, I think, will cover that issue. I think we are in good shape.

Senator KERRY. Will you have funds, for instance, to be able to do research with respect to the impact of the oil spill from the Valdez on the ecosystems on the ocean floor in that vicinity?

Mr. BURTON. Yes. With regard to the Valdez spill, certainly. Number one, we have a body of experts within the National Ocean Service that have developed, frankly, a body of literature that I think is excellent in terms of understanding the impact of oil on the environment, particularly in that area of the country.

Indeed, we recently published a volume, which we could make available for the committee, that specifically addresses the impact of oil on the Gulf.

Beyond that, I should also say that I do not pretend to suggest that the sort of resources that are going to be necessary to conduct a damage assessment, that will take, frankly, years, is in our budget. And we are working, this is off the subject, but we are working right now with the other trustee agencies, as well as Exxon, to put together a fund, an assessment fund that would specifically take care of those budgetary needs.

That is not in the budget. The ongoing base information we think we are okay on; the costs for the assessment we are going to need help for. And signs are that Exxon is going to be forthcoming.

Senator KERRY. In terms of the global warming issue, is there anything in the current body of knowledge or in your current models that says to you—there are steps we ought to take at this time, with respect to fossil fuel burning or carbon dioxide emissions, based on our current understanding of the ocean as a reservoir for carbon dioxide and its relationship to weather patterns?

Mr. BURTON. I am going to take a stab at that, and then invite Dr. Thomas to add anything.

There is no question that the emissions of CO₂ contribute to the fact that the atmosphere warms over time. How much, over time, is owed specifically, however, to manmade emissions versus climate variability, natural variability, is something I am not convinced we have a good handle on. As a result, how much we ought to be clamping down on industry, I would hesitate to say. I would defer to people who are in that business.

Let me ask Dr. Thomas to expand further.

Senator KERRY. Are you doing anything specific on a specific timetable to get a handle on that question?

Mr. BURTON. The whole business of our program in global change is geared to help us understand that as quickly as we can.

We are working hand-in-glove with EPA on the studies they are performing on this, and with the other agencies to have a handle as quickly as we can. In terms of a deadline, Senator, I am not aware that we have one that we are working towards.

I know EPA recently produced a report that suggests there are a number of different things that can be done to reduce global warming. We are commenting on that right now. Those comments, with regard to specific actions in a host of areas, will be in hand by the end of the summer, hopefully by June.

And that report, then, will be made available to the committee.

Senator KERRY. My time has expired on the first round.

Senator Robb has joined us. Before I turn to Senator Gorton for questions, do you have any opening comment at all?

Senator ROBB. Mr. Chairman, I do not have an opening statement. I must tell you that I am here largely out of self-defense. One of my daughters is going to be working up in Woods Hole this summer, and I want to be able to answer some of her questions. Otherwise, I am here to learn.

Senator KERRY. Thank you.

Senator Gorton.

Senator GORTON. Thank you, Mr. Chairman.

Mr. Burton, as you speak about the various levels on which oceans research is being conducted by NOAA, to what extent is there an international interchange of the results of fundamental research in this field? What other nations are engaged in such research with any level of sophistication? Are they duplicating what we are doing, or are they in other fields? And do we have any systematic way of learning from them and helping them to learn from us the answers to what are obviously international questions?

Mr. BURTON. Yes. We are working very closely with a number of different agencies—excuse me, countries in the area of global change. And we think we are in a position to benefit a lot from what they are doing.

Here are a couple of examples. First of all, the TOGA program, which I referenced earlier; the acronym Tropical Oceans and Global Atmosphere.

There are about 15 different countries which participate in that effort. That has been going since 1985. In addition, our scientists are in constant collaboration to exchange information on this very issue: how the oceans, particularly in the tropics, affect the atmosphere, and how, in turn, those combinations affect events like El Nino.

IGBP is another one. We have other activities in the area of climate change right now. Alan, you are going to have to help me with the acronym on IPCC. I believe it is Inter-Governmental Panel on Climate Change, which is a subset of the United Nations Environment Programme.

Meetings have been held, starting last year, on the issue of global warming and ozone depletion. We are in day-to-day contact with that group.

So, in sum, 15, 20, 30 nations at a minimum. We have been working with these matters regularly to understand these dynamics better, which the best example, perhaps, over time, being TOGA.

Senator GORTON. To follow up on that, what other nations are spending any significant portion of their resources on ocean research that is of use to us? What are the other nations that are cooperating in this field and have a considerable interest in it?

Mr. BURTON. The best example that comes to mind, again, in the area of TOGA, has been the French. They have contributed, I would have to provide for the record, Senator, specific numbers, but they have been participants in the effort.

Mr. BURTON. New Zealand has participated in that program. Let me harken back to another example, though, of an interesting area of collaboration. About three years ago, I guess it was, we got together with the People's Republic of China and collaborated on a cruise in the tropics.

The initial cruise started about three years ago, but it is continuing today. They contributed the ship; we contributed the science. The result has been a significant contribution to the body of knowledge. If you wanted to quantify it, it would be about a \$1 million contribution with regard to just that cruise.

But we can quantify more of that for the record if you would like.

Senator GORTON. I am much more interested in your general direction in this connection. Are any of your own planning activities and your own projects affected by the fact that others will either be participating in them or may be doing something which is parallel to them?

Mr. BURTON. Yes. That is necessarily a part of our planning efforts; and, frankly, with a very tight budget that we feel like we regularly have. But we need to plan on what roles other agencies and other governments will be playing.

The World Ocean Circulation Experiment is another area of international cooperation where we have to plan on what roles they will play as we make our plans in preparation for our submission.

So the answer is yes, we try to contemplate and anticipate that before we make requests.

Senator GORTON. What role do satellites play in your research and in your observations?

Mr. BURTON. A significant role—all our meteorological satellites, our GOES as well as our polar orbiters. In the area of the polar satellites, in particular, they provide a wealth of information, Senator, ranging from sea surface temperature, global sea ice, snow cover, cloud cover, precipitation, et cetera, without which it would be difficult to do business.

Senator GORTON. Thank you, Mr. Chairman.

Senator KERRY. Thank you, Senator.

Thank you, Senator Gorton.

Last year the beaches were being filled in a number of communities with waste from medical institutions. Increasingly, questions are being asked about various forms of pollutants that are being dropped directly into the ocean.

Do we, at this point, know enough about the effect? And, if not, are you currently focused on the cumulative effect of the substances that we spil openly into the ocean at this point in time? And is this time to sound the alarm bells with respect to that?

Mr. BURTON. I think the alarm bells have been sounded. We are concerned with the effect. NOAA participated last week in a forum in Hawaii concerned with the issue of persistent marine debris and ocean pollution.

We have been a player with a group of other Federal agencies that has produced a report—if I am not mistaken—that the committee should have received on the issue of persistent marine debris.

Yes, the alarm bell has sounded. With regard, more specifically, Senator, to our Coastal Ocean Initiative, that is one of the hallmarks, understanding better, coastal pollution.

We are appreciative of the role that we have, not of regulating in this area, but understanding the dynamics and elements of ocean pollution better than we do right now. And that is part of our Coastal Ocean Initiative, the request for which is pending before the committee.

Senator KERRY. Have you drawn conclusions that warrant more drastic action than has currently been recommended or taken?

Mr. BURTON. Not at this point, Senator. We are still in the middle of that. I am not prepared to suggest to the committee that we ought to be regulating any more than we are.

Senator KERRY. An alarm bell signals us to take action. It warns, does it not?

Mr. BURTON. Yes, it does. And oftentimes it suggests that perhaps we have not even noticed the problem enough to research it, to understand it, so that we can be prepared to regulate more on it.

I think we are at that stage right now.

Senator KERRY. Well, with respect to that, in the context of the Coastal Zone Management Program, what efforts are being made at this point, if any, to address the question of sea level rise?

Mr. BURTON. The Coastal Zone Management Program, as we administer it, is a grant program. We have no direct spending control over the grants that are given to the coastal States. However, a formal review of each state program is required under section 312 of the Coastal Zone Management Act.

However, we have worked with the States in their grant requests to identify improved coastal land use management strategies including the adoption of set back regulations to deter development in highly winterable areas of the shoreline. I believe the number is about 13 States right now that have put together programs to address the problem of sea level rise through some form of setback requirement for coastal development. We will continue to work with the coastal States that have not put programs in place so far. We can provide those States for the record and give you some specifics on that.

[The following information was subsequently received for the record:]

Thirteen of the states participating in the Coastal Zone Management Program have used funds to develop setback controls for development along the coast in re-

sponse to erosion. However, only Maine has specifically related these setbacks to sea level rise. These are the following participating states:

- | | |
|-------------------|-------------------|
| 1. Rhode Island | 2. New York |
| 3. New Jersey | 4. Alabama |
| 5. Delaware | 6. Florida |
| 7. North Carolina | 8. South Carolina |
| 9. Virgin Islands | 10. Michigan |
| 11. Pennsylvania | 12. Wisconsin |
| 13. Hawaii | |

Senator KERRY. Do you believe you have adequate statutory authority to be able to respond to those problems?

Mr. BURTON. As a regulator, it would be difficult to say because we are not a regulator in the area of coastal zone activity. That activity is deferred to the States.

We do have oversight activity for the Coastal Zone Management Programs that are in place, and we can comment on the adequacy of those programs.

In the fashion I have just described, I think we have been able to provide a useful role in suggesting to the States what activities could be helpful. And in that regard, I would say yes.

Senator KERRY. In what way are you currently taking into account the global climatic change issue, with respect to the management of marine fisheries?

Mr. BURTON. To understand the global environment—as we understand the global environment better and the effect of things like El Nino on fisheries, we will do our job better in fisheries.

There have been a number of examples of how global climatic events have affected fisheries.

Maybe I could ask Glenn Flittner just to mention a couple of those examples. And by those, I think you will see that as we understand global change better, we will do a better job in fisheries.

Dr. FLITTNER. Senator, our ability to monitor global ocean variability is one of the key elements of the activity that the marine fisheries community is most interested in.

As the oceans warmed during the last El Nino cycle, we had major dislocations of fishery resources in the global oceans.

In the Pacific Ocean Basin we had the displacement of tropical species, as much as 1,000 miles farther north on the Pacific coast. And we had disruptions in the salmon migrations into the spawning streams in the Pacific Northwest, especially through the Straits of Juan de Fuca. Under normal conditions, the fisheries are dislocated to the north of Vancouver Island and came in through Johnstone Strait, into the Straits of Georgia, which then render those fisheries vulnerable to Canadian exploitation and not U.S.

These kinds of dislocations are manifestations of ocean climate-induced variability. And these trends have to be monitored, essentially, on a global scale. NOAA has that capacity, especially through its satellite programs, to give us that information, to track those trends.

Senator KERRY. Is that something that you have enough knowledge about to say, I mean, while it happened in the Pacific and up the Northwest coast, that fisheries could be affected almost anywhere where you had that kind of variability?

Dr. FLITTNER. We are not yet at that stage. We have examples that we can point to in the last 20- or 30-year record, but we are

not yet at the point of making predictions, which is what we need to do someday.

Senator KERRY. Can you say how far off you might be, what kind of confidence you have in the current models?

Dr. FLITTNER. I would hate to hazard a guess, but our atmospheric modelers are bringing us closer and closer to an important element of this prediction equation, which is the atmospheric forcing of the ocean.

And I believe in the next decade we will see significant progress in that area.

Senator KERRY. Do you feel compelled by any indices now to suggest that we will need those predictions sooner, that resources should be augmented in such a way as to speed up your ability to be able to make those determinations?

Dr. FLITTNER. I would say that the sooner we can get on with our job, the better. It is of growing importance. On the global scene, we are competing for access to the ocean's living marine resources more and more. And the sooner we know how the ocean impacts on those resources, the more enlightened we will be in carrying out our stewardship role within NOAA for the living marine resources.

Senator KERRY. Do the current trends concern you, Doctor?

Dr. FLITTNER. The trends as you have described them?

Senator KERRY. Or as they have been described by people far more expert than I.

Dr. FLITTNER. The trends are a matter of concern. Yes.

Senator KERRY. How would you characterize that concern? I know there is always this diplomacy that goes on between the committees and the witnesses from the Administration who do not want to be lambasted when they go back to their home ground and told, well, you know, you should not have challenged the Administration on this, or whatever.

But we are looking for real answers here about real problems. And the question is, if you folks cannot tell us that we need more resources in real terms, then we are always going to be doing a dance around this and we are not going to respond to it.

Now, my perception is that this has not been a priority, and that you folks need some money.

Mr. BURTON. Let me try that, Mr. Chairman.

The request that we have before Congress for a \$20 million increase to fund the initiative for global change is, frankly, one of the largest increases in a particular initiative that our agency has asked for, certainly in the immediate past and maybe for a much longer period of time than that.

It represents, indeed, as a result, a significant request. Beyond the issue of levels of funding, however, is just the issue of \$20 million versus \$30 versus \$10. I think what is important for the Agency is to see a steady line of funding.

We started out with an enhancement of \$6 million that the Congress gave us, which was lower than our initial request. We are requesting \$20 million. Whether or not it is doubled, perhaps is less important than to have a predictable stream, and maybe a predictable rise.

Senator KERRY. Well, in the area that we are just talking about, fisheries, was cut in your budget request by 40 percent. That is not

a predictable stream. I mean it is predictable in the wrong direction.

Mr. BURTON. You are right. The 40 percent cut is one that was made on the basis of the decisions that were made in the Department and the Office of Management and Budget with regard to what it felt was important and necessary; what was nice to have versus what we would like to have. Fair enough.

With regard to the global change request, we think that is a fair request for a very important program.

Senator KERRY. Now, in terms of the global change request, you have responsibility for collecting and storing all of the meteorological and geophysical data. Current satellites now collect, you know, one hundred billion bits of data in a single day.

Are you equipped to handle the input of that kind of data that is going to come through the Global Change Research Program?

Mr. BURTON. I think we are in good shape to do that. The National Climatic Data Center in Asheville, North Carolina has, as the committee knows, the largest data collection of global climate data in the world.

That, together with our other centers, the Oceanographic Data Center and the Geophysical Data Center in Boulder, I think represent the best capability available.

Dr. Pyke, I will simply mention, is on the Administration panel on that. Perhaps he would just like to make a brief comment to amplify that.

Dr. PYKE. Yes, Senator, we are very pleased with the role we are playing at the present time. As a manager of the environmental data that we acquire and that others make available to us, both for validation and quality control, and for archiving, we in turn make it available for both research and operational purposes nationally and worldwide.

We feel that we are in good shape to keep up with the volume of data that is coming our way and that we anticipate receiving in the near future.

Senator KERRY. I would be interested to hear later on what the perceptions are of some other folks.

I am delighted to hear that. I am not certain that everyone would believe that, but it is certainly hopeful and I hope it can be done, obviously.

Senator Lott, do you want to ask any questions of this panel?

Senator LOTT. Not at this time. I am just here to listen and learn, and I appreciate the opportunity. Thank you, Mr. Chairman.

Senator KERRY. This will be my last question.

The Washington Post ran a story on the undersea research program suggesting that what the coral reefs were to undersea divers were similar to what canaries were to the mining industry's early research.

Is it your perception that those biological systems could provide the global climate change signal that we have been looking for? Do you find that that is a fruitful area at this point?

Mr. BURTON. We are understanding more about it than we ever have. The National Undersea Research Program, indeed, has funded that.

The coral reefs act in many ways like tree rings, in terms of producing a biological library of what has happened. And, indeed, as you say, are a precursor of what may happen yet.

Again, I will defer to our research expert just to mention a word on it, and then we will provide more for the record, sir.¹

Senator KERRY. Can you share with us any thoughts as to what caused the massive die-off of those reefs?

Dr. THOMAS. Well, I think the best information we have now is that they are very sensitive to temperature changes. Much of the natural variability—we can provide for the record much more detailed results of a symposium that we held with experts in the field.

But it is my understanding that it is part and parcel of the natural phenomenon that occurs in these systems. And, in fact, the bleaching actually gives us a sort of marker in the temperature record, so that it provides us with an idea of what has happened in the past in terms of temperature signal.

[The following information was subsequently received for the record:]

When corals are stressed due to extreme temperatures, their symbiotic algae are expelled, allowing them to devote their resources to survival. It is not clear whether the corals expel the algae or whether the algae release themselves because they are not receiving enough nutrients. Coral bleaching is known to have occurred in 1983 and 1987, and may be tied to El Nino events (most corals have recovered from the 1987 events). It is suspected that bleaching has been occurring in cycles over many years. NOAA is currently supporting research to study the phenomenon of coral bleaching.

Senator KERRY. Before we release this panel, let me ask you if there are observations that you would wish to share with the committee about the global change problem or the climatic change research that you have been charged to do, that you would want this committee to know or understand?

Mr. BURTON. I think it is fair to say—well, let me harken back to the report, Mr. Chairman.

The name of the report keyed, perhaps, the importance this issue has not only for—well, I will put it in reverse order—the Nation, but certainly a key to NOAA's future. It characterizes, I think, fairly well what our mission is: a prediction capability intended to enable the Nation to understand more about the interaction of the ocean and the atmosphere; and predict not only day-to-day as we try to do now in weather, but inter-annually what the climate will be.

That has the potential impact of billions and trillions of dollars on the economy if we have that capability down.

We think NOAA is the agency that has that mission inherent in its charter. And we are excited about the program. We think it is terribly important.

And with regard to a message to the committee, we simply hope that the committee can help understand that role with NOAA, and support it in its request as we seek to do our job.

Senator KERRY. Well, my supposition is that the committee is not going to have difficulty supporting the extra money. I am con-

¹ The material was received and is in the Committee files.

cerned that the advocacy level within the Administration and within NOAA itself, for its own interest, is not necessarily what it ought to be.

I do not disagree with you. We have known for a long time the billions of dollars, literally that are at stake in being able to make these kinds of predictions.

And if we can accurately predict ahead of time what a warming of water off the western coast of South America is going to do to the Northeast coast of the United States, and if we can predict shifts in climate in terms of water availability, that can affect what crops farmers decide to plant, business decisions, planning for water shortage, and so forth.

And it seems to me we have been relatively cavalier in trying to find answers to questions which could have quite significant consequences in the lives of people on this entire planet.

So I am hoping that we are going to upgrade considerably our efforts to find these answers, particularly in view of the fact that some people are predicting that New York and Boston and Florida going to have to build sea walls to the tune of billions of dollars, and that Bangladesh and the Maldive Islands and so forth may disappear within the lifetime of someone born today.

So it occurs to me that I cannot think of anything with a higher priority.

Mr. BURTON. Let me just, if I may, respond one last word for the record, Mr. Chairman.

To the extent it would be suggested you were correct in saying the Administration is being cavalier with regard to the support of this program. In the past I would say that that has been only up until the last year or two when, I believe, NOAA, as well as the other Federal agencies, came to do a much better job, in terms of articulating the problem before us.

And with regard to NOAA, articulating the nature of NOAA's role in this important issue within the Administration. I think we have been effective in articulating the problem, articulating our role. And the Administration has stepped up to a recognition of those issues, as has been presented in the budget request for this next year.

I do not think there is any lack of sentiment on the part of NOAA leadership, and certainly on the part of the NOAA scientists as to what we should be doing and what we will be doing in this area.

I think we are electrified, if I may use that term, on this issue. And we are excited about prosecuting it with all of the energy that we can muster in the coming months and years.

Senator KERRY. I want to thank you for taking the time. We will leave the record open for the submission of written questions. I appreciate your testimony.

I would ask the next panel to please come forward.

Thank you.

We will have to try to move along a little quickly here because we have a couple of back-to-back votes coming up, I think in about 45 minutes. So I want to try to keep going, if we can.

Thank you all for your patience. I appreciate it.

Dr. Wallace, do you want to lead off? Is that the game plan here?

**STATEMENT OF JOHN WALLACE, DIRECTOR OF JOINT INSTITUTE
FOR STUDIES OF THE ATMOSPHERE AND OCEAN, DEPART-
MENT OF ATMOSPHERIC SCIENCES, UNIVERSITY OF WASHING-
TON, SEATTLE, WA**

Dr. WALLACE. Thank you, Mr. Chairman and Members of the Committee.

I am John Wallace, a Professor at the University of Washington, and Director of the Joint Institute for the Study of the Atmosphere and Ocean.

I am very grateful for the privilege of having a chance to talk to you today about global change.

From your introductory remarks, it is clear to me that you and the Committee are well aware of the importance of global change and the broad, interdisciplinary aspects of this problem.

We need to draw upon disciplines like fluid dynamics, physics, chemistry, and biology, in order to deal with a broad range of problems in the atmosphere, the oceans—the oceans playing a central role in this—the polar ice caps, and the land vegetation, together acting as a system that has a life of its own, which transcends the individual pieces of the spheres that we are working in. It is like a giant puzzle that we are just learning how to solve.

In the process of trying to provide predictions of global change on these long time scales, and, in particular, predictions of the impacts of human activity, we have to learn how to observe this complex, intricate system in a way that it has never been observed before; and we have to learn how to simulate it with numerical models that, in time, we hope will become the models that we can use for prediction of future change, just as we use models today for the prediction of day-to-day weather changes with considerable success.

I share the view of the previous panel: speaking now as a person outside NOAA, as a university person, that I agree NOAA should be the lead agency for the national research program in climate change.

I believe that NOAA has capabilities to lead this effort that no other single agency has, and certainly that we do not have in the universities. Those capabilities include not only the ability to take global observations and archive the data—capabilities that have been very much emphasized in previous hearings. But I want to stress that NOAA is also a leader in research, particularly research directed toward prediction.

NOAA has the premier group in the development of atmospheric models and coupled atmosphere-ocean models as well, and is really leading the national effort in the development of models capable of predicting the ocean and its interaction with the other elements in the climate system.

Personally, I am concerned about NOAA's ability to lead this effort right now, even in the face of rather substantial increases that we see in this year's budget and hopefully next year's budget. Those increases have to be balanced against the considerable budget cuts that have occurred in the last couple of years. These cuts, which have been largely across-the-board affect all elements in the agency, and they have had the cumulative effect of weaken-

ing the infrastructure that supports some of the national laboratories.

As a result, when new money comes in for a new program, we get into inevitable conflicts between the laboratory directors and the directors of the various line organizations within NOAA who, quite justifiably, are trying to hang on to every penny that they can to preserve the infrastructure against this erosion that it has experienced.

On the other hand, the program directors of these new programs, who want to get to see some results for the money they are putting into them. I think until the administration takes a close look at the infrastructure of NOAA and makes a commitment to keep it strong, we are going to have this conflict, which I think is compromises NOAA's ability of the agency to really lead effectively in this effort.

So, that is the most important point that I want to make in my testimony.

My own involvement with climate research has been in connection with the TOGA program, which has been previously mentioned. I see TOGA as an element in global change.

In a way, you could think of the global change problem as a giant puzzle that we have to solve, which does not have any edge pieces. We have to start somewhere in putting pieces together, and, in the absence of edge pieces, the only thing one can do in a puzzle is to find some pieces that have compatible sets of colors, hopefully perhaps some colors of different types, and put them together and begin to make a sub-assembly. Then one can make a couple of sub-assemblies, and, ultimately, we would hope would be able to put all the pieces together.

TOGA is a piece of the puzzle that includes some of the atmosphere, some of the ocean—specifically, the tropical ocean—and the very interesting way in which they come together to produce a kind of variability on the year-to-year timescale that is totally unlike anything that the atmosphere or the ocean could produce by themselves.

And so, I think of TOGA as a building block that forms a prototype for the development of interdisciplinary programs which, together, can then be merged to form the whole of the global change program.

[The statement follows:]

Senate Testimony on Global Change and TOGA Research Programs April 6, 1989
by John M. Wallace, Professor of Atmospheric Sciences, University of Washington

1. What is TOGA

TOGA is the acronym for the international research program directed at the understanding of the interactions between the *Tropical Oceans* and the *Global Atmosphere*. It spans the decade 1985-95 and involves substantial contributions from the U.S., PRC, France, Japan, Australia, New Zealand and a number of developing countries including Peru, Ecuador, Chile, Brazil, India, Indonesia and several Pacific Island nations.

The primary goal of TOGA is to improve climate prediction on the seasonal and interannual time-scale. The relationship between tropical sea-surface temperatures and climate anomalies such as droughts over the tropical continents is quite strong. For example, warm SST anomalies over the equatorial Pacific often referred to as El Niño events tend to be accompanied by heavy rainfall along the coast of Ecuador and at islands in the central equatorial Pacific, and drought over Australia, Indonesia, India and parts of Africa. Relationships with climate fluctuations over extratropical regions such as North America are not as strong, but they are still good enough to be useful in prediction. For example, El Niño winters tend to be mild over the northwestern U.S. and cool and wet in the southeast. There is also some evidence that SST anomalies in the equatorial Pacific contributed to the drought over much of the north-central U.S. during the spring and early summer of 1988.

The components of the TOGA program are

- a) observations over the tropical oceans, with emphasis on the distributions of surface wind, sea surface temperature, ocean currents and subsurface thermal structure.
- b) numerical modeling directed toward the simulation of the coupled atmosphere/ocean system and improved climate prediction.
- c) empirical studies of relationships between tropical sea surface temperature anomalies and global climate anomalies, and
- d) process studies designed to elucidate the mechanisms responsible for the coupling of the atmosphere and ocean in the tropical belt.

Most of the TOGA research effort in the U.S. has been devoted to the El Niño/Southern Oscillation phenomenon over the equatorial Pacific but U.S. investigators are also involved in studies of phenomena in the tropical Indian and Atlantic Oceans

2. TOGA and Global Change

In order to make reliable predictions of global change on the interdecadal time scale it is going to be necessary to improve our understanding of the various linkages between the atmosphere and the other components, physical and chemical, of the coupled climate system: most notably, the oceans, the polar ice caps, and the biosphere over land. In my view, progress on this problem will not come from attempts to design, in a single step, the ultimate global observing system and the all-encompassing model of the linkages in the climate system. Rather, I believe that knowledge will be built up step-by-step by considering one linkage at a time in the context of real climate-related phenomena and learning how to observe it adequately and how to represent it in numerical models. The TOGA program can be viewed as an effort to understand one of these linkages. The observing system that is being developed for TOGA will be an essential component of the global observing system needed to monitor global change; the coupled atmosphere/ocean models being developed under the sponsorship of TOGA will ultimately be elements or modules of more comprehensive models of the climate system; and the process studies supported by TOGA have direct applications to our understanding of climatic variability on the interdecadal timescale.

Hence it is appropriate to view TOGA as a component of the Global Change program, focused on a specific problem from among the suite of problems that have to be considered in order to understand and predict climate variability on the interdecadal time scale. TOGA offers a substantial payoff in its own right, in the form of improved seasonal climate prediction, and it offers a specific opportunity to learn how to do the interdisciplinary type of research required for Global Change. In my view, one of the most notable achievements of the TOGA program is the creation of a community of researchers dealing with a class of fundamental, climate related problems that transcend their parent disciplines. I view such interdisciplinary research communities as nuclei which will, in due course, grow into larger, the multidisciplinary research effort needed to effectively address the issues of Global Change.

The management structure of the TOGA Program can also be viewed as a worthy prototype for a Global Change program. The U.S. program is coordinated by a national program offices which is housed within NOAA. It has fostered cooperation between scientists in the national laboratories and the universities, and between federal agencies (NOAA, NSF, NASA, ONR). And it has been effective in promoting U.S. interests in the international TOGA Program and in building international support for the program.

3. Current Status of TOGA

TOGA is currently undergoing a mid-life review at both the international and national level in order to assess what has been accomplished during the first five years, and what needs to be done during the remaining five years of the program. The review process is still in its early stages, but I think I can predict some of the points that are likely to emerge.

Thus far in the program we have witnessed one moderately strong warm episode (1986-87) in the equatorial Pacific and one strong cold episode (1988). As a result of TOGA these events have been monitored better than any previous event. Notable achievements in the monitoring include: the first large-scale monitoring of the ocean; improved fields of sea-surface temperature and surface winds over the equatorial Pacific; more effective use of oceanographic measurements through the use of a real-time data assimilation scheme analogous to the ones used operationally for some years now in weather prediction; establishment of a number of new surface and upper air sounding stations in the equatorial Pacific; a number of new equatorial current moorings and improved collection of oceanographic XBT data from commercial ships. The emphasis on the collection and analysis and distribution of data in real or near real time represents a virtual revolution in the way oceanographers do research and share their results with the community. In the modeling, there has been a major breakthrough in our understanding why the coupled/atmosphere system exhibits such large year-to-year variability in the Pacific. Some progress has also been made in understanding and predicting the links to middle latitudes, but not as much as we had hoped, because the problem has proved to be more difficult than anticipated.

Looking ahead to the next five years, there is need for further improvements in our ability to monitor surface winds over the tropical oceans. In the short term, a network of moored buoys with wind instruments may be the best prospect for the equatorial Pacific

region, while in the longer term many of us still hold the hope that satellite sensing of surface waves will provide fields of surface winds over the whole world ocean with a level of accuracy better than anything that we have a reasonable hope of achieving with surface based instrumentation. Unfortunately, the launching of the spacecraft that will fly this instrumentation has been delayed until near the end of the TOGA period. We also look to future satellite measurements for improved monitoring of tropical precipitation, which is of critical importance for determining the state of the atmosphere.

More work is needed to refine the procedures for assimilating surface wind data into atmospheric numerical weather prediction models and ocean models in real-time. Without such an effort it would be difficult to justify additional expenditures for improved measurements.

The remaining five years of TOGA is likely to see an increasing amount of experimentation with more realistic coupled atmosphere/ocean models capable of simulating phenomena such as El Niño. Additional experimentation will also be needed in order to define to what extent and under what conditions climate anomalies over North America can be specified on the basis of a knowledge of the tropical sea-surface temperature distribution.

Additional process studies are needed in order to better understand some of the specific linkages between atmosphere and oceans. A Coupled Ocean/Atmosphere Response Experiment (COARE) has been proposed for the western equatorial Pacific for the early 1990's and is currently under review. It would involve a 3-6 month period of intensive observations from research vessels, moored buoys, instrumented aircraft, weather radar designed to examine atmosphere/ocean coupling on space and time scales much finer than can be resolved with conventional data sets.

Prediction will continue to be the major thrust of TOGA. During the remaining years of the program I believe that much of the effort in the program needs to be devoted to improving the skill of predictions ranging from days out to a year or two, making use of our expanding capability for observing and modeling the tropical atmosphere and oceans.

4. The Role of NOAA

Since this Committee bears the responsibility for the oversight of the Department of Commerce, I would like to address my final remarks to the issue of the role of NOAA in TOGA. I believe that NOAA is uniquely qualified to be the lead federal agency in TOGA. It is the only agency that has sufficient manpower and resources to mount the major efforts that are required in the areas of observing system design and implementation, data management, data assimilation, experimental climate modeling and operational climate prediction. Specific capabilities include

- o experimental climate prediction (Geophysical Fluid Dynamics Laboratory, Princeton and Air Resources Laboratory, Boulder)
- o observing network design, moored and drifting buoy development and deployment, automated surface stations (Pacific Marine Environmental Laboratory, Seattle, Atlantic Oceanographic and Meteorological Laboratory, Miami)
- o empirical studies, operational diagnostics and climate forecasts, assimilation of ocean data, preparation of sea-surface temperature and tropical rainfall data sets (Climate Analysis Center, Washington, D.C.)
- o operational analysis of surface winds (National Meteorological Center, Washington, D.C.)

It is worth emphasizing that NOAA's capabilities are essential not only in the areas of observing and data management, but also in many critically important areas of research such as experimental climate forecasting.

Climate prediction on the seasonal, interannual, and interdecadal time-scales is a natural extension of NOAA's mandate to provide weather forecasts on a day-to-day basis. But at the current levels of funding, one could seriously question whether NOAA is in any position to take on these new responsibilities in climate prediction without compromising its ability to deliver accurate and timely short-term weather forecasts and warnings. Across-the-board budget cuts, together with inflation, during the past few years have seriously eroded the support base of the NOAA Laboratories. This situation is resulting in increasing conflict between the lab directors, who are desperately struggling to maintain decent levels of staffing and support services in their laboratories and the TOGA and

Global Change program directors, who justifiably want to see the funding that they provide to the laboratories used for specific research projects that contribute to the objectives of their programs. Hence, if NOAA is to be able to provide effective leadership for a new U.S. program in Global Change, I believe that the funding base for the NOAA research laboratories needs to be restored to levels of a few years ago, in addition to whatever incremental funding becomes available for specific new research initiatives.

Dr. WALLACE. I have a set of four transparencies with which I was going to try to illustrate some aspects of this prediction problem. I think, in the interest of time, I would show those only if there is interest on the part of the Committee in seeing them. I think the combined time that it would take to see them would be three or four minutes.

Senator KERRY. Let's do that.

I think it would be interesting and helpful.

Dr. WALLACE. This speaks specifically to the El Nino problem, which is a part of the TOGA problem.

[Slides shown.]

Dr. WALLACE. In the first transparency, I want to show you the distribution of sea surface temperature over the Pacific in two contrasting sets of years.

The upper panel represents the cold years, sometimes referred to as the non-El Nino, or even La Nina, years, like 1988. These contours here [indicating] represent lines of constant temperature.

This area in the Western Pacific, inside this contour, is the warmest part of the Pacific. The temperature is like a bathtub, about 85 or 86 degrees Fahrenheit.

Over on the eastern side of the Pacific where I have shaded it here [indicating], temperatures are in the 60's, along the coast of South America.

This is the upwelling area [indicating], a very rich area for fisheries, this cold water. Penguins live in the Galapagos Islands.

So we have this strong temperature contrast across the Pacific.

Now, in a warm year, or in an El Nino year, like 1986 and 1987, we see that the warm water has sloshed eastward here, into the middle of the Pacific, and the cold water has retreated. The retreat of the cold water along the South American coast has major implications for the fisheries there, as has already been mentioned.

As I will show you in the next transparency, the movement of this warm water from the extreme Western Pacific to the Central Pacific has enormous implications for world weather patterns.

I am going to try to superimpose on top of this a transparency that schematically shows where it rains in the tropics during these two sets of years.

First, during the cold year on the top [indicating], most of the rain is back over in Indonesia. We think of this as sort of a normal situation, very much like what we have had this past winter. The Central Pacific is dry. In fact, there are islands in this slot here [indicating], in between these rain belts, that are virtually like desert islands during the cold years.

Senator KERRY. How many years are you talking about that are cold years?

Dr. WALLACE. It would be, say, the coldest half of the years. I think we could roughly say that in half the years, the picture would look like this [indicating the panel for the cold years], and in something like half the years, maybe a little less than half, it would look like this [indicating the panel for the warm years]. Examples are 1986-87 and 1982-83.

You will see how in the picture for the warm years the heavy precipitation has moved over to the Central Pacific with the warm water. It likes to stay on top of the warm water. We have drought in Indonesia and parts of Northern Australia at these times. These same desert islands in the Central Pacific then get more rain than we do anywhere in the continental United States—10 or 15 inches a month, month after month after month, on some of these islands, during these warm years.

This shift in the precipitation has implications for the whole distribution of the monsoons throughout the tropics. The warm years tend to be deficient in rainfall over India, and over parts of the Sahel, and they tend to have flooding along the South American Coast.

Senator KERRY. Were there leading indicators of these transitions, or were they very sudden?

Dr. WALLACE. These transitions occur usually during our summertime, and they occur over a period of three or four months. Usually by, say, September or October of a given calendar year, we can pretty well anticipate what the pattern is going to look like for the next six months or so.

So already, even with our limited knowledge, we have some forecast ability. It is around that time of year, around September, when school is just starting, that my children ask me every year, are we going to have any snow days this winter; are we going to get to stay home from school.

We do live in the Pacific Northwest, a part of the country that is affected by these swings in precipitation.

In a normal year, I am showing you here the jetstream level pattern, and these contours represent stream lines. There is air flowing off Asia across the Pacific here [indicating] into the United States. In a cold year, the air comes straight in, and we get a series of storms off the Pacific, and it is usually rainy here in the Northwest. But occasionally we do get snowstorms in this situation, and we get generous snow pack in the Pacific Northwest, and winter-time climatic conditions are what we think of as fairly normal and benign over most of the United States.

Now, during the warm years, like 1986-1987, we get this wave that is built up over the Rockies here [indicating]. Instead of the flow coming straight in, as it did in the previous slide, with the storm track coming straight into the Coast, the storm track gets deflected up along the Canadian Coast here [indicating], and most of the storms go up into Canada. We get much milder than normal weather, and the snow pack is deficient. The Gulf States get more precipitation than normal. They get a sort of southern storm track that forms here [indicating]. That seems to be quite a noticeable and consistent effect.

So, like in 1986 and 1987, when my children asked me in September, are we going to get any days off from school, I said probably not this year. This does not look like a good year. In 1988, when it was already apparent in September that we could look more toward a pattern like this, I would be able to say well, there is maybe a better chance than normal.

Senator KERRY. How far back have you gone to look to see whether there is a correlation pattern?

Dr. WALLACE. Back to 1950 or thereabouts. I would say on the record for that period in which we have about 15 or 20 of each of the two types shown here, we have a batting average of about 75 percent. It is not a perfect forecast tool by any means. But on the basis of what we know now, we could make that kind of forecast in September and say "mild and dry" for the Pacific Northwest, or "cool and wet," and have a batting average of, say, 70 or 75 percent.

In the tropics, the forecasting is much better. If you were forecasting rainfall in these tropical islands that I mentioned, you would be 95 percent accurate, and we think we can push the odds up a bit more as we get to build better models of this phenomenon and be able to anticipate these changes a little further in advance.

Senator KERRY. Do you know yet or have any indications yet what causes the temperature shift in the water itself or the movement of the large bodies of cold and warm?

Dr. WALLACE. It is a feedback process between the atmosphere and the ocean. In fact, in showing these transparencies, I just described it and did not have a chance to go through the reasoning of what is happening.

But, essentially, the surface winds have a very strong effect upon the distribution of sea surface temperature, and, in turn, the sea surface temperature has a large effect on the distribution of precipitation. Ultimately, the precipitation affects the surface winds. And so, it's like a dog chasing its tail here [indicating]. We go around the loop.

We cannot really describe it in terms of the atmosphere doing something to the ocean alone, or vice versa. We have to build models of the whole, coupled system. In the last couple of years, there have been some really exciting developments in that area which suggest types of instability which we are just beginning to understand, which appear to be capable of producing this large variability from year to year.

Senator KERRY. That relationship obviously just underscores even more how critical it is to get a handle on what happens. As more and more CO₂ goes up, as the greenhouse effect alters the atmospheric input more, you could be altering obviously the entire relationship.

Dr. WALLACE. That's right, and things that we have not even thought of at this point could prove to be important, either enhancing the sensitivity of the system or perhaps in going the other way, letting us off easier than we might have expected.

We have no way of knowing at this point that we have really covered all of the bases.

Senator KERRY. Thank you, Doctor. That is very interesting.

Who is next? Will it be Dr. Brewer?

Please proceed.

STATEMENT OF PETER G. BREWER, SENIOR SCIENTIST, WOODS HOLE OCEANOGRAPHIC INSTITUTION, WOODS HOLE, MA

Dr. BREWER. Thank you, Mr. Chairman.

Mr. Chairman, Committee Members, I am Peter Brewer from the Woods Hole Oceanographic Institution. Mr. Chairman, I have prepared written testimony, and if I might here, I would just show a few quick viewgraphs.

Senator KERRY. That would be very helpful. Thank you. Your full written testimony will be printed in the record.

Dr. BREWER. Thank you.

Mr. Chairman, I will try to be brief with a few highlights on the cycle, as seen from the point of view of an ocean chemist.

This is, in fact, the kind of data that NOAA produces on the atmosphere. You have all seen this many times.

Senator KERRY. Can you speak up just a little bit.

Dr. BREWER. Yes.

[Slides shown.]

Dr. BREWER. This is one of the manifestations of global change. It is a NOAA science product. To my mind, it is one of the crown jewels of American science. It is a marvellous record.

If you look at things like this, we would like to try to divine what the role of the ocean is, what the role of the land is, and maybe what the role of legislation could be in affecting a cycle of this kind. In order to do so, we have to get deep inside the record and read this like a book.

When we do so, we really have problems.

I am going to focus on the ocean side for a moment, and just show you some of those.

First, we do have to get data from the oceans to answer that, and we had a question, I believe from Senator Gorton, earlier on about international manifestations. This is a cruise that is taking place at the moment. The picture is not focused too well here. I hope that is better.

Canada, United Kingdom, Germany, United States, and the Netherlands are all taking part in this. We are about a 25 percent player. Based on the funding situation and other problems, there was concern as to whether we could even show up. It is a real problem.

The ships that we work with are not really adequate for the job, but we are trying.

Senator KERRY. Whose ship is this?

Dr. BREWER. This is a Woods Hole ship, the Atlantis II. We have it for three months. It is small and it is not really adequate.

We are looking here at one corner of the ocean for one year, trying to make sense of it.

Let me show you some of the issues that we have to deal with.

My guess is that we would have to have the lights out to do this justice. It is a satellite image of the North Atlantic Ocean in two seasons, winter and summer. It is a NASA product.

You can see the North Atlantic is blue in winter and green in spring, just like the land. You are looking at plant chlorophyll.

We need sensors like this to understand what is going on in the world. The satellite that produced these images is now dead. We hope for a new satellite, Sea-WIFS to be launched in 1991, on LANDSAT VI. Right now, I cannot guarantee that. The negotiations are bogged down.

Without it, we will not be able to do our work.

If you will look at images like this and try to translate them into what we know of the ocean carbon cycle, they start to tell you some very strange things.

For instance, I first saw this image in an airport in Paris. I sat down and wrote a paper, which tried to apply what we know of the physics of the North Atlantic to describe the chemistry.

What I found was that we had some very nasty mass balance problems. If you want to know how sensitive these systems are to change, you first have to answer some basic questions: do the numbers add up?

At the moment, I would say that we have a major mass balance problem in putting conventional physics into describing the carbon cycle problems that we have.

Senator KERRY. Give us an explanation of what is indicated in each of those, would you?

Dr. BREWER. You are looking at chlorophyll as seen from space. You are looking at a chemical jet, originating in the Gulf Stream, off Florida, and shooting northwards off the U.S. East Coast.

The warm surface layer is cooled by dry continental air, coming off the U.S. continent, and, as it cools, deep mixing starts to occur. The deep mixing brings up the chemical species, nitrate and phosphate, and that allows the plants to grow once the water stabilizes in the spring.

So you are seeing two things—the physics of the Gulf Stream jet moving northwards, in the summertime—

Senator KERRY. Where is that indicated? Can you point to it?

Dr. BREWER. Yes. You can see here [indicating] the lack of the green color. The blue color here means there is no chlorophyll off Florida. It shoots northwards at very high speed. As we get off the U.S. East Coast, we have taken off the heat from the surface ocean and allowed the deep water to be exposed. As we do so, the plants are allowed to grow, until, by the time we get right across the ocean, we have these very strong green blooms, just like you would on the land, with the blooming of the crops in the springtime.

Senator KERRY. And what you found disturbing about this was what?

Dr. BREWER. If I sat down and applied the numerical models which have been accepted for the flux of heat in the Atlantic Ocean, and have been found to be quite acceptable, and I applied them to the chemical species, I found chemical imbalances that did not make sense. This told me, for instance, that we are not really playing with a full deck when we claim to be able to model the ocean's chemical cycles.

We had to significantly revise the physics in order to try to bring the chemical cycles into approximate balance.

This tells us, then, if we had to ask in some adversarial mode, can you get mass balance in your system—an elementary high school question—that right now, we cannot.

Senator KERRY. And going further, translating that into a sort of public policy issue, what is the meaning of that to me and to the other Senators on this Committee?

Dr. BREWER. I will get to that in just one moment, Senator.

May I just raise one other question?

Senator KERRY. Absolutely.

Dr. BREWER. We are talking of a warmer world. We would like to be able to answer questions such as what are the temperature dependence of the reactions that you are seeing here. The answer is: I don't know.

What we are going to have to do is mount the kind of expeditions, put in the kind of technology that you are seeing here, if we are going to have any hope of understanding and predicting the change.

I would like to address the policy issue briefly. This is a very old slide that I pulled out for the occasion.

I thought you might ask this question.

It is the carbon history of our century. It is the rate at which carbon is burned by our industrial society worldwide.

We are talking of intruding on this by legislation, as we would like to moderate the effects. Take a look at what it takes to do that.

You can see in there World War I. It was a sharp rise. We burned a lot more carbon.

The Great Depression was a horrible time. Things went down a bit.

Senator KERRY. Is World War I the first curve?

Dr. BREWER. Yes, that's right.

World War II shows it up sharply again; reconstruction was a little dip. Then the post-war society is showing upwards enormously.

I believe that we can pass legislation that will help us with the freons. We have done that. We can probably make a dent on the methane, and we can do a few other things.

But to try to intrude on this system is going to be very difficult.

I would support legislation to try to produce a more efficient and less wasteful society because it is a better way to live.

But we should not believe we can press on this too far. We do not want economic upheavals of the scale of the Great Depression. Moreover, other societies—the Soviets, the Canadians—could very well benefit from a warmer world, and might cheerfully just burn as much as they could.

In fact, there is some evidence of policy issues of this kind.

If we are in a world where there are policies of this kind being implemented, we would like to know what the result will be. If, for instance, you tell me that the country went nuclear, we used fluorescent lightbulbs everywhere, we raised the fuel average economy to 50 miles per gallon, and you brought me back here ten years from now and asked how are we doing, I would tell you that we live in a better world, but the CO₂ signal has gone up.

So, the message is that we should prepare to live in a warmer world, we should prepare for global change, and we should try to inform ourselves quite a bit better as to what the effects will be.

At the moment, I am not sure that we can do that.

[The statement follows:]

Global Change: The Relevance of Oceanic Chemical, Geological and Biological Processes

Introduction

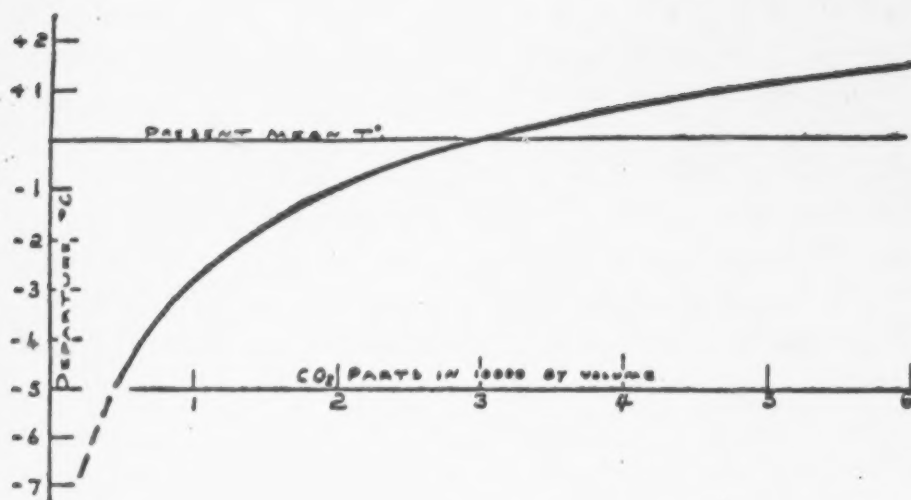
Senator Kerry, thank you for the opportunity to testify at this hearing. I am Peter G. Brewer, Senior Scientist at the Woods Hole Oceanographic Institution in Massachusetts. I serve as Chairman of the U.S. Global Ocean Flux Study (GOFS) Committee, and as Vice-Chairman of the international Joint Global Ocean Flux Study (JGOFS), a ten member nation scientific committee charged with investigating the role of the ocean in global change, the topic before us today.

In this testimony I seek to touch on three principal themes: to illuminate the scientific relevance of oceanic chemical, geological and biological cycles to global change, to comment briefly on U.S. policy responses to such events, and to review the status of ongoing and planned research efforts within our federal agency structure. I do so from the point of view of an ocean chemist with long experience both in the mounting of large-scale oceanic scientific expeditions and in the difficult science of unravelling the oceans' carbon cycle.

The somewhat strident debate in the media over the past year or so over "Is it warmer now?" should not be allowed to obscure some basic chemical operations, nor the scientific history of our century. An excellent review of the greenhouse theory of climate change by V. Ramanathan appeared about 1 year ago (1); the roots are traced to the last century. The scientific concensus over this effect has in fact remained remarkably constant for decades, yet the expressions of concern from our knowledgeable scientists have greatly increased and it is instructive to ask why this may be so.

For an interesting example I refer to a seminal paper in this field written by G.S. Callendar (2) two years before I was born; it represents the view of my father's generation. Callendar, armed only with a slide rule, computed the effect of rising CO₂ levels on surface

temperatures. I show his result in Figure 1.



With remarkable economy of means this antique figure shows a result little different from the supercomputer runs of today. This shows two things: that the fundamental result is robust, and that expansion upon it is hard, for vastly more complex questions are asked of such calculations today. For a shock, however, we turn to the next page where a prediction of the rate of change is given, also reproduced here.

TABLE VI.—INCREASE OF MEAN TEMPERATURE FROM THE ARTIFICIAL PRODUCTION OF CARBON DIOXIDE.

Annual excess of CO_2 to the air = 4,300 million tons.

$P(\text{CO}_2)$ is expressed in units of a ten-thousandth of an atmosphere.

ΔT = increase from mean temperature of 19th century.

Sea water equilibrium time 2,000 years.

Period	1910-1930	20th century	21st century	22nd century
Mean $P(\text{CO}_2)$	2.82	2.92	3.30	3.60
Mean ΔT , °C. . . .	+0.07°	+0.16°	+0.39°	+0.57°
Polar displacement of climate zones. . .	15	36	87	127km.

Several things have now gone wrong. The mean $p\text{CO}_2$ of 360 ppm envisaged by Callendar as characterizing the 22nd century, will be reached before the end of the 20th; it is approximately 355 ppm today. We are more than 100 years ahead of schedule, and accelerating. We have also discovered a suite of companion gases, methane, nitrous oxide and CFC's which are cumulatively equal and additive to CO_2 . And importantly, we have changed our view of the ocean. Callendar assumed a 2,000 year equilibrium time for absorption of CO_2 and heat. We now know the circulation is much more rapid; elegant tracer studies have shown that while regions of the deep Pacific are older than 1,000 years with respect to ventilation with the atmosphere, the mean value is close to 550 years. Thus the extraordinarily rapid chemical forcing of the atmosphere has been somewhat balanced by an unanticipatedly vigorous ocean. This, most emphatically, does not solve the problem, but it may help explain why the projected equilibrium thermal signal is yet delayed. In allegory with an "Alice in Wonderland" world, the smile has emerged and the Cheshire cat is lagging just behind. It is the sure knowledge that we have already bought into change, with the effects yet to be felt, that so concerns our scientists.

For those still skeptical I urge them to check their stock portfolios. Like millions of American citizens I own shares in a mutual fund, and recently checked to see what the managers had bought. Stocks of industrial corporations whose product lines featured infrared gas analyzers figured prominently. Those are good, useful and profitable devices that monitor our workplaces. They work very well and depend upon fundamental principles identical to those discussed here.

Role of the Ocean

The role of the ocean in this scheme is hugely important, and at first deceptively simple. At the most basic level we are carrying out a giant chemical titration of the alkaline ocean with acidic CO_2 gas. The alkalinity of the ocean provides the chemical buffer capacity, and the rate at which this capacity can be brought into play is a function of the ocean's physical circulation (3). The result of this complex interplay is that today the ocean appears to take

up some 45% of the fossil fuel CO_2 signal released annually; were it not for this massive effect we would be in a much less stable world. The surface waters of the ocean have become more acidic, by about 0.07 pH units, since the turn of the century and contain some 10% less carbonate ion. We compute this, but do not know it from direct observation.

At this point it is useful to make a clear distinction; so far as we can tell the invasion of CO_2 into the ocean takes place today purely as a passive tracer, inserted inexorably by thermodynamic equilibrium, and transported into the oceanic abyss by the massive oceanic planetary circulation schemes. CO_2 does not fertilize the ocean; it is already present in massive amounts as a natural state. As we change the chemistry of the upper ocean the buffer factor (the ratio of the fractional change in the atmospheric property to the fractional change in the oceanic property) will also be perturbed and atmospheric CO_2 levels will tend further to rise. The ocean will tend chemically to resist change. We understand this quite well.

More problematic are the rules governing the natural cycles of carbon in the ocean, and the sensitivity of these cycles to change. We know that the reservoir is massive, more than 50 times bigger than the atmosphere, and has fluctuated in the past—most notably in concert with the last ice age. In this matter we are perplexed; we do know that the natural cycle of carbon is intimately linked to that of the elements oxygen, nitrogen, phosphorus and sulfur, and that limitations in the supply of nitrogen, and to a lesser extent phosphorus, to the surface ocean control oceanic plant (plankton) growth, thus controlling the carbon cycle. We can paint a picture—climate warming changes ocean circulation (including vertical mixing), this changes the rate of supply of nitrogen, and this alters oceanic life cycles and the flux of carbon. We tend to believe this would further elevate CO_2 levels in the atmosphere. Yet so difficult is the problem that no responsible scientist could speak with certainty.

For these reasons two principal themes of oceanic research emerge: knowledge of the cycle of carbon and related biogenic elements, and knowledge of the physical circulation. These two must be linked through sophisticated data assimilation and modelling techniques,

and must depend heavily on advanced observing technologies including satellites and *in situ* observations.

The geological cycles of the ocean must be accounted for also, though possibly with a different view in mind.

The most important signal from the geologic record is that it permits us to read the carbon cycle of the past. Cores from the ocean floor contain marvelous information, albeit transcribed through a complex filter. We do not know if we can equate a natural change in the past to a man-made change in the very near future. One thing we learn is that massive amounts of calcium carbonate sediments have come and gone in response to climate change. The ocean floor will tend to dissolve in the more acidic ocean we are creating and the question is whether this will significantly restore chemical capacity and buffer against change. The best estimate is that while this is possible in principle the practical effect will be very small indeed (4).

Implications for Policy

Scientists should venture into policy considerations only with the utmost caution, yet they are often forced to do so for a curious, yet quite understandable, reason. When scientists approach legislators they are usually seeking funding; what they usually get is legislation. The problem is then what to do with it. In the case of global change the focus is almost universally on moderating the effect. There are excellent reasons for prudence, conservation and substitution of harmful chemical species, which no intelligent person could deny. In the unique case of CO_2 , however, we run directly into the enormous consequences for our energy intensive economy; events of the scale of wars, or the OPEC oil shortage of the 70's, put only a ripple in the massive signal. Are we prepared to intrude beyond that?

Before committing an altruistic act we should look beyond our shores, and at other times. In the earlier cited paper Callendar (2) for instance, while confessing

"...it almost impossible to account for movements of the gas of the required order because of the almost inexhaustible supply from the oceans"

when describing an ice age, opined that he was quite optimistic of the warming suggesting the effect

"...is likely to prove beneficial to mankind in several ways ... for instance, ... at the northern margin of cultivation. In any case the return of the deadly glaciers should be delayed indefinitely."

Today we smile tolerantly at such naiveté, and remark upon rising sea levels. However, there are other voices; in the Soviet Union Academician M.I. Budyko has recently spoken in favor of rapid elevation of CO₂ levels (5) and against

"...expensive and economically disadvantageous limitations in the development of carbon energetics aimed at retarding or terminating anthropogenic climatic changes."

He concludes

"...it is probable that the most advantageous decision would be not to retard but intensify the growth of CO₂ concentration, which would rapidly result in the reconstruction of the Pliocene climatic optimum conditions which are more favorable than the modern ones."

The paper is possibly given tongue-in-cheek, and is surely designed to provoke genuine debate. But it alerts us to the need to think well beyond unilateral action. It is a sobering thought that this particular future is not in our hands.

The wisest course at this time therefore seems to me to invest in knowledge—genuine, rigorously evaluated knowledge that is fully accepted within the international arena, and can lead to concerted policy.

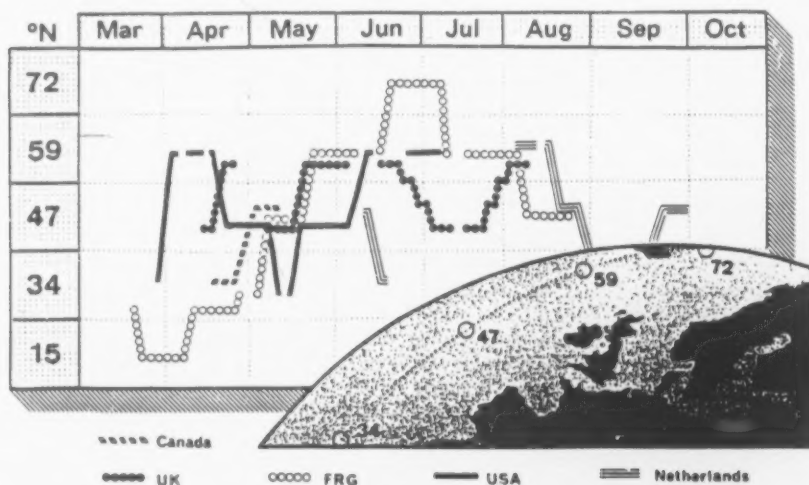
Status of Ongoing and Planned Research Efforts

There are many relevant U.S. research efforts, and certainly no shortage of voices on these matters. I rather suspect that there are more committees than there are scientists

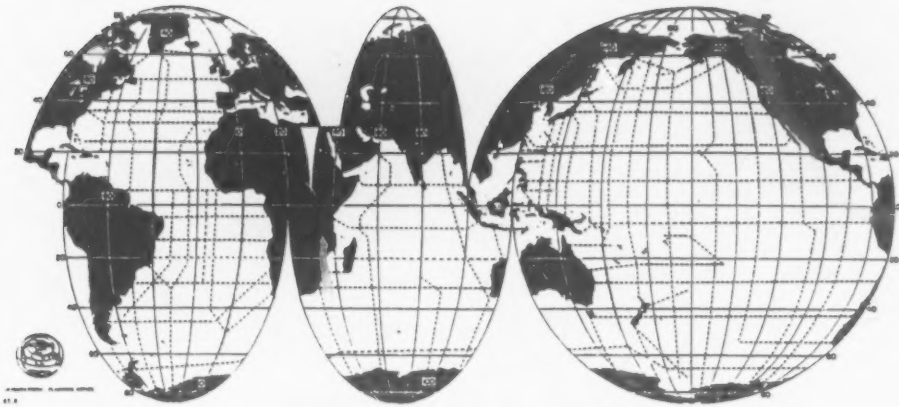
skilled in this difficult field. I commend to you two major ocean observing experiments that will provide essential knowledge, the Joint Global Ocean Flux Study (JGOFS) and the World Ocean Circulation Experiment (WOCE). Both are fully international, have been long in planning and set high standards for excellence and discipline of their participants (6).

You will hear more of JGOFS from my colleague Hugh Ducklow in this same hearing. I show here the cruise tracks for the pilot program in the North Atlantic, with scientists at sea while I speak. The experiment leads the way for an international study of the oceanic carbon cycle in all its forms.

For WOCE the object is the determination of the circulation of the oceans on a global scale. The data are essential for the problems we discuss here, and the numerical assimilation of carbon, and other chemical, data into the models prescribed follows quite naturally. The proposed cruise tracks for WOCE are also shown here.



JGOFS Pilot Study in the North East Atlantic, 1989. Cruise transects and stations around 20° W (except Canada, 55-40° W) with NASA aircraft overflights at 34°, 47° and 59° N between late April and early June.



I would like here to dispel the notion some may have that such exercises are sterile data collection schemes. They, most emphatically, are not. The planning and execution of a modern complex, international field program is a bruising, draining and demanding intellectual adventure of the first rank, involving the assemblage of diverse and complex technologies, and rigorous assessment of what they can deliver. Those scientists at sea also face human challenges of the most basic and elemental kind.

A major research need is to fulfill the mandate of such experiments. In attempting to do so we are stretched dangerously thin. A colleague recently asked me for comment on our dealings with federal agencies and in a moment of candor I replied that I was a scientist at a private institution, supported by the National Science Foundation, working to get a privatized NASA instrument on a NOAA satellite, and observing the signals from a Navy owned ship with DOE funds! It could be easier; and I fear that a great deal of the creative time of our scientists goes into resolution of such problems.

Our program officers at NSF and NASA are of exceptional quality, yet are frequently placed in impossible situations. Thus, the U.S., after leading the way in creating and

planning such ventures, is often regarded internationally as an unreliable partner with genuine concern expressed as to whether we can even show up.

Research Needs

- Satellite Observations

Satellite observations of the ocean are an essential ingredient of modern science relating to global change. The recent release of ocean color images on a world-wide scale from the Coastal Zone Color Scanner (CZCS), a now defunct instrument, has marvelously stimulated interest in the oceanic carbon cycle and has filled a major gap in oceanic observational technology. The need is for a new instrument, SeaWiFS (Sea-viewing, Wide Field-of-view Sensor) to be flown on the NOAA Landsat 6 platform in late 1991. The privatization scheme proposed for this instrument through Eosat Corporation is novel and complex; many of us fear that it will bog down. Without this our ability to extrapolate ship observations to large scales will be greatly reduced. The TOPEX mission, for satellite altimetry of the oceans and essential for WOCE, is similarly strained.

For the future NASA is proposing the Earth Observing System, a large and complex mission for the period 1996-2006, which incorporates ocean sensors of greater spectral range. This is an exceptionally interesting and important mission and we will work diligently with this new development. However the relatively modest missions above must come first if we are to have any hope of dealing with the future data.

- Data Assimilation and Modelling

In the matter of data assimilation, modelling and interpretation a significant investment is needed. Numbers are not automatically knowledge, and the road to insight is hard. Our data management, computing and analyzing capabilities should be broadened widely.

- Ocean Observations

The experiments mentioned earlier require ships. While I yield to none in my admiration for the job done by the officers and crew of our academic fleet, the blunt truth is that they frequently must maintain old, inadequate and dirty vessels in a hostile environment. Somehow I suspect we have simply set wrong standards; our colleagues in Canada, Europe and Japan are often better equipped with modern, clean research ships. It is possible that the present mid-life refit and stretching of two of our research vessels, the R.V. KNORR and R.V. MELVILLE, will go some way towards remedying this, but it is a short lived, retrospective solution.

- New Observing Technologies

The atmosphere is far easier to observe than the ocean. Too much science in the ocean still must be done by laborious manual operations. We will require an investment in moored and drifting instrumentation to capture signals in remote places and over longer times.

Federal Agency Roles

The experiments I describe above depend principally upon the National Science Foundation, and a significant partnership with NASA. You have asked me to comment on the role of the National Oceanic and Atmospheric Administration (NOAA) in a national global change research effort. In all candor, I find it hard to think of a single NOAA; the agency consists of many parts, of differing degrees of excellence. I am also acutely aware of low morale in agency ranks from shifting priorities and funding stress. This is disturbing for there are essential needs to be met. NOAA's Global Monitoring for Climate Change Program provides accurate data on the worldwide distribution of atmospheric greenhouse gases; the program could be enhanced and expanded.

The successful cooperation between NASA and NOAA in flying the SeaWiFS ocean color sensor on Landsat 6 is crucial to programs such as JGOFS. NOAA has also been of signal help in providing a JGOFS field coordinator for the North Atlantic Experiment described

earlier. Scientists at the NOAA Princeton Geophysical Fluid Dynamics Laboratory excel in data analysis and modelling, and deserve strong praise.

While it appears to me that the above functions are basically in place and deserving of support there are other areas not yet well represented. Research, for instance, on the class of problems representing the oceanic biogeochemical cycle. I have seen draft documents describing a proposed NOAA thrust in this direction and my initial impressions are quite favorable. For such a venture to be successful a partnership with academic scientists would likely be a necessary ingredient, and this has indeed been discussed.

Senator, I thank you again for this opportunity, and hope that my testimony has been of help to this committee.

Footnotes

1. V. Ramanathan. The greenhouse theory of climate change: a test by an inadvertent global experiment. *Science*, Vol. 240, p. 2293-299, 1988.
2. G.S. Callendar. The artificial production of carbon dioxide and its influence on temperature. *Quarterly Journal of the Royal Meteorological Society*, Vol. 64, p. 223-240, 1938.
3. P.G. Brewer. Carbon Dioxide and the Oceans. In: *"Changing Climate", Report of the Carbon Dioxide Assessment Committee*. National Academy Press, Washington, D.C., p. 186-215, 1983.
4. E.T. Sundquist. Geological perspectives on carbon dioxide and the carbon cycle. In: *The Carbon Cycle and Atmospheric CO₂: Natural Variations Archaen to Present*, E.T. Sundquist and W.S. Broecker (eds.), American Geophysical Union, Geophysical Monograph 32, 1985. Dr. Sundquist's report to the NAS Ocean Studies Board CO₂ Panel, 3/15/89, confirms that we can expect very little amelioration of the CO₂ rise from carbonate dissolution over the next few centuries.

5. M.I. Budyko and Yu.S. Sedunov. *Anthropogenic Climatic Changes*, a paper given at World Congress, Climate and Development, Climatic Change and Variability and Resulting Social, Economic and Technological Implications in November 1988 at Hamburg.
6. Detailed accounts of the planning of the experiments may be obtained from: U.S. GOFS Planning Office, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, and U.S. Planning Office for WOCE, Department of Oceanography, Texas A & M University, College Station, TX 77843.

Senator KERRY. Thank you.

I am going to hold off on my questions and try to get back to this subject afterward.

I will try to get now to Dr. Ducklow and Dr. Bretherton.

STATEMENT OF HUGH DUCKLOW, ASSOCIATE PROFESSOR, UNIVERSITY OF MARYLAND CENTER FOR ENVIRONMENTAL AND ESTUARINE SCIENCES, HORN POINT ENVIRONMENTAL LABORATORY, CAMBRIDGE, MD

Dr. DUCKLOW. Thank you, Senator Kerry and Members of the Committee, for the opportunity to testify.

I would like to carry on from some of the things Peter Brewer was talking about and emphasize a few points about the role of oceanic biological processes in global climate change. These are all spelled out in much more detail in my written testimony.

Currently, as a result of fossil fuel burning and other less well understood reasons, atmospheric CO₂ levels are rising very rapidly, and we know that the inescapable result within 50 to 100 years will be global warming of a magnitude unsurpassed in the last 150,000 years.

Senator KERRY. Let me stop you there for one moment.

Is that assuming things stay exactly where they are today? Is that just with what is currently released in the atmosphere, even if you were to reduce? What is the supposition on which you say within the next 50 to 100 years, massive global warming will be automatic?

Dr. DUCKLOW. I think the situation is a little uncertain, but with the current levels of CO₂ in the atmosphere, we do expect a significant warming, even without any further fossil fuel addition.

Senator KERRY. And that remains true, even if we met the year 2000 chlorofluorocarbon goal? Let's say we reduced CO₂, and the CAFE standards go up, and so forth. You would still have that warming?

Dr. DUCKLOW. That's correct.

Senator KERRY. Can you place the range? I mean, you hear various scientific predictions of degrees. Is there a range that, with accuracy, this panel would agree on?

Dr. DUCKLOW. That is a question for Dr. Bretherton.

Senator KERRY. All right. I'm sorry to interrupt you.

Dr. DUCKLOW. Our general understanding of the global carbon system is good enough to allow us to diagnose this present-day situation as follows. Changes in the amount of carbon dioxide in the atmosphere are a major cause of global climate change, and oceanic processes are a key factor modulating those atmospheric CO₂ changes.

One key process is the rate of carbon dioxide removal from the atmosphere into the deep ocean, and this is ultimately controlled by marine photosynthesis. That is the fixation of carbon dioxide into plant tissue by phytoplankton in the ocean, and the subsequent sinking of this plant tissue into deep water. This mechanism is known as the "biological pump."

I have a slide which I can show on that.

Senator, that big curved arrow there, that goes down from the atmosphere into the ocean, is the passage of CO₂ into the ocean by biological fixation. As you can see, most of that material is returned ultimately to the atmosphere by a normal biological process called "respiration," which is what you and I do when we breathe out.

You see a small arrow coming out and going into the deep ocean. That is the biological pump. That is the mechanism that we are concerned with for global change on longer timescales, of decades to centuries—the removal of CO₂ from contact with the atmosphere on longer timescales.

One of our big problems is that we don't know the width of that arrow. We don't know the strength of the biological pump.

What we do know from studies of ice cores and the geological record is that when the biological pump is functioning efficiently, atmospheric CO₂ is low; and when it functions inefficiently, atmospheric CO₂ is high.

That controls the transition from glacial to inter-glacial.

At the moment, we are adding a lot of extra CO₂ to the atmosphere, and we would like to know how the oceanic biology responds to that question.

Thus, changes in oceanic primary productivity influence the global climate. But our understanding of the specific biological and physical mechanisms is not adequate, and we cannot predict the future course nor the effects of global warming on the atmosphere-ocean system.

Senator KERRY. Are you able to say how far we are from creating a model that will permit us to do that?

Dr. DUCKLOW. I would say that we are some years away from just collecting the data we need to validate such a model, and we are several years away from having a model that couples atmosphere and ocean physics with biology and nutrient cycling.

The first generation of those models are just now being run. Our greatest need to understand that effort and to get these products are much better estimates of primary productivity, the global photosynthesis in the ocean. Our current estimates of global primary production may be in error by as much as a factor of ten.

The main reason for this is a gigantic undersampling of the world ocean. We just cannot get to every place we need to over the course of a year or geographically to specify that number. And so, satellite coverage is required urgently.

This is a counterpart to the picture that Dr. Brewer showed. It shows you the global biosphere, both the oceanic plant biomass and, for comparison, the terrestrial biomass as well, the plant tissue. What we would like to draw your attention to is the green and yellow in the North Atlantic, compared to some of the greening in the Northern Hemisphere. As some of the other speakers mentioned, the ocean blooms with plant life in the spring, just like the land does.

This revolutionary view of global biology was provided by the Coastal Zone Color Scanner, which is now dead. The next ocean color sensor is slated to fly on the LANDSAT VI vehicle in 1991, and it is currently in jeopardy of not being built.

Saving this sensor, the Sea-WIFS, requires prompt action by your Committee, by NOAA, and by other Federal agencies. We cannot do our jobs, as Peter Brewer said, without this view of the world provided by our remote sensing of ocean color.

Long-term, multi-agency commitments are also needed to support large sea-going in situ research programs, like the World Ocean Circulation Experiment, and the Joint Ocean Global Flux Study, which you have heard about. These are also needed to put ships and scientists in the ocean, to validate the satellite information, to provide the details of these mechanisms that we need to predict the future course of global warming.

One example is the JGOFS North Atlantic Bloom Study. Peter showed you the cruise tracks for this. It is a large international program, of which the U.S. is one player. This program is a pilot study for other future studies over the decade of JGOFS. It's object is a better understanding of the spring bloom phenomenon.

This appears to be one of the major global mechanisms of atmospheric CO₂ removal. But we do not know the magnitude of this process.

In my written testimony, I list some other critical research needs for these programs and some of the ways in which NOAA can further these efforts.

Senator, in conclusion, given the prospects before us, we need to consider new policies to predict, plan for, and cope with climate change, and the greatest priority is support for a greatly expanded program of scientific research, especially the remote sensing and sea-going programs that I have described.

Thank you.

[The statement follows:]

STATEMENT OF DR. HUGH W. DUCKLOW, UNIVERSITY OF MARYLAND CENTER FOR ENVIRONMENTAL AND ESTUARINE SCIENCES, HORN POINT ENVIRONMENTAL LABORATORY, CAMBRIDGE, MARYLAND

Thank you, Senator Kerry for the opportunity to address the Senate Committee on Commerce, Science and Transportation. My name is Hugh W. Ducklow and I am an Associate Professor at the Horn Point Environmental Laboratory of University of Maryland Center for Environmental and Estuarine Studies. I am also a member of the Executive Committee of the US Global Ocean Flux Study and the US Coordinator of a major international oceanographic expedition now underway, which I will describe in my testimony.

Senator Kerry, in past testimony presented before this committee you have heard about our current understanding of global change, about new international initiatives to study it, and about the importance of a new generation of remote sensing satellites for documenting and understanding it. In my letter of invitation to this hearing, Senator Hollings asked that I discuss our current scientific understanding of the role of living marine organisms in ocean-atmosphere processes, the links between ocean productivity and climate, and the influence of coastal pollution on the climate system. This is a very tall order, so I will just try to emphasize a few of the most pressing areas of uncertainty, and then describe some of our research needs in these areas. I will conclude by recommending how the National Oceanic and Atmospheric Administration can help us meet these needs.

THE CARBON CYCLE AND CLIMATE.

Even young children have been exposed to the idea of global climate change. It has long been taught that the dinosaurs perished because the earth became inhospitable for them. Thus the notion of a changing, evolving planetary environment is basic to popular beliefs about our world. The earth has evolved as a highly integrated system, the major elements of which are the atmosphere, the oceans, and living organisms, especially micro-organisms which create and decompose organic matter and control the fluxes of oxygen, carbon dioxide (CO₂), methane and other gases between the atmosphere, biosphere and oceans. Marine plankton are major engines of global climate change. Within the past decade a series of scientific discoveries, and growing awareness of the unprecedented effects of mankind on the heat and carbon cycles of the oceans and atmosphere have energized scientific and political consideration of the causes, effects and future directions of global change. Understanding the role of the oceans in regulating the global climate is a key to these concerns.

Studies of the composition of air bubbles trapped in ice cores show unequivocally the strong relationship between the CO₂ content of the atmosphere, the global mean temperature and the advance and retreat of the glaciers. These observations tie the heat-trapping efficiency of the atmosphere (the "greenhouse effect") to major episodes of global change which affect the conditions of life and evolution. These episodes involved massive transfers of carbon between the atmosphere and oceans. The ocean is the earth's major reservoir of carbon containing over 90% of the actively cycling carbon on the planet. The implication of these observations is clear: ocean biogeochemistry is a principal mechanism of global climate change.

THE ROLE OF LIVING MARINE ORGANISMS IN OCEAN-ATMOSPHERE PROCESSES.

There are two principal kinds of exchanges between the CO₂ in the atmosphere and the oceanic carbon reservoirs: 1) the biological transformation of CO₂ into living tissue and skeletal material by photosynthesis (primary production) and its return to solution via respiration and decomposition, and 2) its passage across the air-water interface and dissolution in ocean water. This latter process is also biologically controlled in part because CO₂ enters the sea only when the gas already in seawater is undersaturated with respect to the air above. Photosynthetic "fixation" of dissolved CO₂ is the process causing that undersaturation. For governing climate change on a scale of decades to centuries, the most important processes are those which move carbon from the atmosphere into the deep sea (below about 1000 meters depth). This is because deep ocean water only circulates back to the surface and exchanges its heat and gas content with the atmosphere about every 1000 years. Organic carbon fixed during photosynthesis sinks from the surface into the deep sea, where it is eventually respired back to CO₂. As a result of the biological removal of CO₂ from surface waters and respiration in deep water, there is a gradient of increasing concentration of CO₂ with depth in the ocean. The sinking of organic matter through the water column "pumps" carbon against this gradient. CO₂ dissolved in surface seawater can also be conveyed to depth by the sinking of the cold, dense water in high latitude regions of deep watermass formation.

Clearly the most important things we need to understand about the role of biological processes in the carbon cycle and climate change are the rate of photosynthetic fixation of CO₂ into biomass, its geographic and seasonal distribution, its annual, global mean value, and the physical, geochemical and biological mechanisms governing those variations. In the ocean photosynthesis is carried out principally by unicellular phytoplankton in the upper 50-100 meters of the water column which is illuminated by sunlight. Seagrasses, seaweeds and coral reefs

are of local or regional importance, but their geographical extent is so small compared to the area of the deep open sea that they contribute only 1-2% of the total marine production. Currently, the rates of global primary production are thought to be accurate only within a factor of 2-10.

The uncertainty in specifying the rates of primary production are due partly to the difficulty in measuring photosynthesis reliably, and more significantly, to a severe undersampling both geographically and seasonally. Logistical considerations limiting our sampling ability include the remoteness of many areas and the great problems associated with obtaining data in winter when it is often too rough to conduct shipboard observations. The USA is currently experiencing a severe shortage of research vessels and other platforms for extending observations throughout the world. There are only a few locations where primary production has been measured over the course of a full year or more with acceptable temporal and depth coverage to allow good annual estimates. In many areas of the world's oceans, including some thought to be most important (high latitudes, equatorial regions), few measurements have been made.

The Biological Pump.

Even if we had a vastly improved description of oceanic primary production, we would still not possess the ability to predict future changes in climate or their effects. This is because not all the biomass produced by phytoplankton is removed from contact with the atmosphere for more than a few days to weeks. Only the fraction of the primary production which eventually sinks or is advected through the water column into the deep sea participates in the longer-term aspects of the carbon cycle relevant to climate regulation. The sinking fraction is composed of dead phytoplankton cells, the fecal products, molts and carcasses of grazing animals which eat phytoplankton and each other, and amorphous aggregates of microorganisms and dead organic matter. These substances are referred to as the vertical, or sinking flux and can be collected in sediment traps moored to the sea floor or left to drift for varying periods of time. The sinking flux is the biological pump which transports organic matter into the deep sea reservoir.

Only a few per cent of the surface primary production eventually reaches all the way to the ocean floor, the remainder having been respired back to CO₂ along the way down. The key quantity though, is the amount of the sinking flux exported from the upper few hundred meters. This amount is very poorly known. The size of the sinking fraction is set by a very complex interaction of factors including the physical mixing of the water column by wind and heat loss, the biology and physiology of

zooplankton and bacteria, the structure and dynamics of food-webs, and the seasonal evolution of the species composition of the phytoplankton.

Measurements of these phenomena are in their infancy. Most measurements of either primary production or sinking fluxes have been made in summer and in the tropics or subtropics, where (or when) it is estimated that about 5-20% of the primary production is exported to the deep sea. There are very few data from high latitudes or winter when we expect the sinking fraction is much higher. The most advanced models of planktonic ecosystems predict that the annual sinking flux even in the subtropics may be 40-60% of the total production. Advanced geochemical methods based on tracer distributions predict a similar fraction. Without a much better characterization of the oceanic production system worldwide, we cannot effectively budget the global carbon cycle and cannot accurately specify the role of oceanic biology in regulating future climate change.

LINKS BETWEEN OCEAN PRODUCTIVITY AND CLIMATE.

Since biological processes in the ocean play a role in governing climate change, and are also obviously affected by changes in climate, the ocean-climate system has important and interesting feedback mechanisms. Changes in climate will affect the ocean, including its biology, in presently unforeseen ways. The attendant changes in biological rates and processes, especially biological "pumping" of carbon into the deep ocean, will affect the ocean-atmosphere coupling of CO₂ exchanges. This in turn will cause subsequent changes in the evolution of the climate system. Partly because of our inability to predict the effects of global warming on ocean circulation, and because we do not understand oceanic biology well enough, we cannot say with any certainty whether these feedback mechanisms are self-stabilizing (negative feedback, like a thermostat) or self-sustaining, (positive feedback, like a thermonuclear chain reaction). Also, we cannot yet specify the sensitivity of oceanic biology to climate changes. Some examples are presented to clarify the problem.

Recent models of ocean circulation and nutrient content point out the great importance of high latitude regions of watermass formation in governing the long-term behavior of the global carbon cycle, and thus of climate change. These regions appear to be of great importance because most of the volume of the ocean eventually returns to contact and equilibrium with the atmospheric CO₂ content in just a few high latitude regions of the world, principally in the North Atlantic Ocean and some areas around Antarctica. Biological processes in the surface and deep water which modify the nutrient content of the sinking "new" water have been shown in models to cause large excursions

in atmospheric CO₂ content. In particular, higher biological activity in high latitude surface waters will lead to a decrease in atmospheric CO₂. Thus if global warming leads somehow to higher levels of production at high latitude, the effect of the biological response would be to lower atmospheric CO₂ levels, and subsequently, ameliorate the warming trend. Conversely, if the coming global warming trend decreases production or water-mass sinking in these regions, the trend will be amplified. At present we cannot say which way global warming will push primary production. It is important to note here that models of greenhouse warming predict the greatest warming at high latitudes where the system is most sensitive to biological changes.

Another interesting effect concerns the potential role of biogenic sulfur gases in climate regulation. Many groups of phytoplankton produce dimethyl sulfide (DMS), a volatile compound which is emitted from the ocean into the atmosphere. The highest emission rates are from the warmest waters. DMS is oxidized in the atmosphere to produce an aerosol which contains nuclei for cloud condensation. Put simply, under certain circumstances, primary production may help to increase cloud cover, especially at higher ocean temperatures. Increased cloud cover increases the reflectance (albedo) of the planetary surface, thus having a net cooling effect. Again, this is an example of a negative, or stabilizing feedback loop, in which global warming leads to increased cloud cover and subsequent cooling. There are major uncertainties associated with this scenario as well. Anthropogenic sulfates released from fossil fuel combustion also produce cloud condensation nuclei. Their emission exceeds that from marine sources by a factor of two and is almost entirely confined to the Northern hemisphere. If DMS plays the hypothesized role in regulating the planetary albedo, then anthropogenic sulfates should also. But no increase in either cloud cover or mean temperature has been observed in the Northern Hemisphere relative to the Southern, suggesting that for whatever reason, the DMS-cloud cover mechanism is not operating, or that some unknown countervailing process is balancing it. One attraction of the DMS hypothesis is that it is testable by studies of ocean plankton and remote sensing of ocean color, clouds and temperature. But we need the resources to begin such studies.

INFLUENCE OF COASTAL ENRICHMENT ON THE CLIMATE SYSTEM.

The enrichment of the coastal zone with plant nutrients is another global scale perturbation associated with human activity. The evolution of agriculture and urban development have resulted in large increases in nutrient and topsoil runoff in historical time, and especially in the past 50 years. The rate of primary production over continental shelves is about four times greater than in the open sea. The shelves cover about 7% of the area of the oceans, so about 20-25% of the global primary

production occurs over the shelves. However it has been estimated that perhaps half of the total primary production is exported from continental shelves into deep water, compared to 5-20% commonly assumed for the open sea. Therefore it is possible that about half of the global sinking flux is generated over the shelves, with some unknown fraction being the result of nutrient enrichment derived from anthropogenic sources on land. Coastal zone production enhanced by cultural eutrophication has thus been hypothesized as a major global sink for atmospheric CO₂.

There are several difficulties with this scenario. The major uncertainty is over the levels of total primary production over the shelf-slope regions of even the better studied areas like the eastern USA where much research has been conducted. Other shelves (around Antarctica, off Argentina and in the Eastern Pacific) remain much less well characterized. The amount of production exported off the shelves into the slope and open ocean regions is not well-known and very hard to estimate as much of the off-shelf transport may occur in brief episodes following storms. Finally the fate of the anthropogenic enrichment is unclear. Some of the resulting production is more likely to be respired over the shelves and not conveyed into the deep ocean. Therefore it is not at all certain that enhanced production in the coastal regions has an effect on climate. But given the increasing pollution of the ocean margins, where over half the world's population resides, and the importance of shelf areas for food production and waste disposal, the potential links must be explored.

RELATED RESEARCH EFFORTS.

All the issues discussed above: global primary production, the biological pump, the importance of processes at high latitudes and in coastal areas, and the DMS link between phytoplankton and clouds, are affected in a significant way by a major biological episode occurring annually in the oceans. This is the spring phytoplankton bloom, an event analogous to the budding and regrowth of leaf cover on land in the temperate and boreal latitudes each spring. In winter the surface layers of the ocean outside the tropics are recharged with nutrients by winter mixing of deep water from storms and convective heat loss. Triggered by increasing sunlight under conditions of nutrient saturation and low grazing pressure, phytoplankton growth "explodes" leading to the accumulation of plant biomass. This annual pulse of primary production supports many commercial fisheries. During the bloom, CO₂ is withdrawn from the atmosphere into the ocean to replace that incorporated into the phytoplankton. Atmospheric CO₂ fixed during the bloom ultimately sinks into the deep sea. One group of bloom phytoplankton called

coccolithophorids are important producers of DMS and also secrete skeletons of calcium carbonate. Thus the bloom process helps to regulate the atmospheric CO₂ levels and climate change.

The bloom process has long been studied over continental shelves, where about half the annual production is generated in a few weeks or months. Its occurrence in the open sea was less certain. However results from long-term deployments of sediment traps below 3000 meters have demonstrated unequivocally that a pulse of heavy sedimentation of dead phytoplankton happens annually. This is clearly tied to oceanic blooms and represents an important fraction of the total annual flux of carbon into the deep sea. This indirect hint of phytoplankton blooms in the open ocean was dramatically confirmed by the first composite basin-scale images of the North Atlantic from the Coastal Zone Color Scanner (CZCS) which flew on the NASA Nimbus-7 vehicle. As a result of the remote sensing of ocean color by the CZCS we know that the spring bloom is the major seasonal biological signal in the global ocean. These observations suggest that spring phytoplankton blooms may generate a large fraction of the annual carbon flux which couples the atmosphere and ocean carbon reservoirs. Spring blooms are a major contributor to the biological pump.

The Joint Global Ocean Flux Study.

A new multidisciplinary international scientific program, the North Atlantic Bloom Experiment (NABE), has recently begun the first basin-scale exploration of the spring bloom phenomenon and its significance for the oceanic carbon cycle. This program, supported principally by the National Science Foundation and NASA with other support from NOAA and the Office of Naval Research, is the first active research program of the Joint Global Ocean Flux Study (JGOFS), now a part of the International Geosphere-Biosphere Program (IGBP). An increasing number of nations, including the Soviet Union and the People's Republic of China, have representatives on the JGOFS governing committee. Besides the USA, Canada, the Federal Republic of Germany, The Netherlands, Great Britain and France are participating formally in The North Atlantic Bloom Experiment, with additional individual participation by guests from Iceland, Japan, Portugal, Sweden and the Soviet Union.

NABE represents the principal US scientific effort aimed at understanding the ties between biogeochemical cycles and climate change. Spring blooms are just one of the problems we need to solve for a better understanding of the links between the oceans and climate. A much larger effort is needed. These problems are too big and too complex, and our understanding is still too primitive, for the USA to address them alone. International efforts are crucial to the success of these programs and to understanding future global climate change. The USA launched the

Global Ocean Flux Study and still leads that effort. Other nations have joined enthusiastically and are now making large and valuable contributions. The Bloom Experiment is a pilot study for the decade-long JGOFS program, and a large input of new resources and financial support are needed to establish a truly global program.

Using US participation in JGOFS as a focus, I would now like to describe some of the highest priority requirements for an effective component of a global change research program, particularly as it involves a better understanding of the interaction between global ocean productivity and climate change.

MAJOR RESEARCH NEEDS.

Needs described below are grouped into three categories, based on the objectives of the US Global Change Research Program: a global observing system, focussed process studies, and modeling and prediction.

Global Observing Systems.

* Enhanced remote sensing capability.

The NASA SeaWiFS (Sea-viewing, Wide field-of-view sensor) instrument and its projected successors on the Earth Observing System for remote sensing of ocean color are critical elements for projected studies of global scale change in the ocean. The SeaWiFS is scheduled to fly on the NOAA Landsat 6 vehicle in mid-1991. It is the principal tool for extending our sampling reach to previously unexplored regions of the oceans and for deriving more precise estimates of global primary production. This instrument is vitally needed to specify the regional extent, timing and persistence of the spring bloom. It is also an invaluable tool for guiding in situ studies on research vessels. Without this and future color sensors there will be no truly global studies of change in the oceans. The USA pioneered this technology, and still is the world leader. Without it, the USA will yield the position of leadership in space and ocean research it has held for some time. If and when the SeaWiFS does fly, a significant increase in support for calibration and validation studies is required for successful use of the data it will collect. These related studies require new platforms in the oceans, including ships, untended moorings and permanently manned observatories.

* Ocean observatories.

We require long-term monitoring of a wide range of ocean properties and processes. Not all can be observed from ships or space. A network of manned observatories equipped with

high-quality laboratory facilities based on islands (Bermuda, Hawaii, etc.), drilling rigs and other large platforms is needed to provide the documentation of global change and to support process studies in areas not continuously accessible by ships.

* Moored environmental sensing systems.

Many oceanic properties can be observed nearly continuously by unattended instruments. A global network of moored instrument packages, including sediment traps, meteorological and optical sensors and chemical and biological analyzers are required to extend our observations in remote locations, to document seasonal and longer-term pattern in ocean physics, chemistry and biology. New sensors must be developed to observe properties not yet routinely measured.

* Data management.

These studies and satellites will produce an unprecedented volume of data on the ocean. A much improved capability for assimilating, analyzing, archiving and distributing data rapidly throughout the international scientific community is required if we are to derive any value from the projected research programs.

Focused Process Studies.

Prediction of global change requires mechanistic understanding and not merely documentation. Understanding of causes and mechanisms can be most effectively gained through a series of intensive process studies like the JGOFS Bloom Study and elements of WOCE. An aggressive effort on the part of all the Federal agencies to identify, support and pursue specific ocean process studies is needed to provide the scientific foundation for interpretation of the data products collected by the global observing system.

Process studies demand complex measurement and experimental programs carried out aboard research vessels. Much of the US academic oceanographic research fleet is antiquated and in poor condition, very limited in ocean-going capability, and not suitable for supporting many state-of-the-art studies. Europe and Japan have large, modern new scientific research vessels far superior to ours. In the next decade there is a vital need for extended studies to validate the remote sensing efforts and map the CO₂ content of the oceans with large-scale surveys. Especially considering the many global oceanographic programs planned for the next decade (JGOFS, WOCE, TOGA), new vessels, refits for existing vessels, and better operating support are vitally needed.

Without a new generation of ships and satellites, and an aggressive program of process studies in the 90's, the USA will lose its leadership role in oceanography and global change research.

Modeling and prediction.

The overall goal of all the other needs and studies is to predict future changes and understand the functioning of the climate system. Global-scale models of coupled ocean-atmosphere circulation integrated with advanced representations of foodweb dynamics and nutrient cycling are critical tools for predicting the effects of global change on the oceans and atmosphere and for understanding the mechanisms of global change in the ocean-atmosphere system. The first generation of these coupled physical-biological models is just now being developed. Right now, the general circulation models of the ocean-atmosphere system are more accurate than the biogeochemical models. Integration of these separate elements is vitally required to develop the earth system models called for in the US Global Change proposals. A wider effort is needed to train modelers in the relevant techniques, equip them with supercomputers, and support the analysis and validation of the model results.

THE ROLE OF THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA) IN A NATIONAL GLOBAL CHANGE RESEARCH EFFORT.

With respect to the uncertainties in our present knowledge as discussed above, the needs just described and the strengths of NOAA, the following are some priorities for NOAA ocean studies in the next decade. Again, these are grouped into the three objectives of the US Global Change Program. In general, NOAA should join other agencies to foster better and closer coordination among all government agencies for supporting an integrated plan of global change research.

Global Observing Systems.

- * Ensure the continued cooperation between NOAA and NASA to place the SeaWiFS ocean color instrument in orbit in 1991 aboard Landsat-6, to receive the data, and to support validation studies.

- * Help establish and maintain a network of moored instrument arrays and manned observatories to monitor local, regional and global trends and changes in the ocean and atmosphere, including parameters currently not measured on a routine or continuous basis (e.g., total water column sections of carbon distribution at selected long-term sites).

* Improve our ability to collect, assimilate, analyze, archive and distribute oceanographic data. An important early goal in this area is to collect and validate the quality of the historical database on primary production and phytoplankton biomass, and integrate it into the CZCS database.

Focussed Process Studies.

The full participation of NOAA in active research programs is needed for the US to meet its goals for the Global Change Program. NOAA's past experience with TOGA is an excellent model of its ability to contribute to process studies. NOAA must enhance its collaboration with other agencies and especially with the academic community in the support of specific ocean process studies like JGOFS and WOCE, which are relevant to the goal and objectives of the US Global Change Research Program. This includes strong efforts in ocean circulation, the role of the marine environment in the global carbon cycle, and climate-biological interactions including the marine phytoplankton-DMS-climate link. NOAA participation in this area should include a strong extramural grants program which will enhance the cooperation and collaboration of NOAA PI's with their academic counterparts in research on ocean processes, and the prediction of climate change and its regional implications on timescales of seasons to decades to centuries. In this regard, some of NOAA's current research efforts in the coastal domain should be redirected toward similar areas of importance to studies of global change.

Models and Prediction.

NOAA's role as the principal operational agency for prediction of ocean and atmospheric processes mandates a strong demonstration of their leadership in national and international efforts to develop and apply predictive models of the integrated earth system. NOAA can help to improve our ability to understand and predict global change by developing, analyzing and validating better global models of oceanic circulation, biogeochemistry and ecology.

In planning and implementing the programmatic elements required to fulfill these responsibilities, NOAA must continue to demonstrate leadership in fostering the development and execution of the US Global Change Research Program through the US Committee on Earth Sciences.

CONCLUSIONS: POLICY IMPLICATIONS OF THE CURRENT UNDERSTANDING.

As a result of more than a century intensive burning of fossil fuels and deforestation, mankind is causing the CO₂ content of the atmosphere to rise at unprecedented rates to its highest value in the last few 100,000 years. It seems certain that in the next few decades human civilization will experience climate changes greater than at any time in recorded history. The social, economic and political consequences of global warming, sea level rise, desertification and the shift of crop growing regions will be enormous. It is already too late to halt or reverse the present trends, though perhaps some can be slowed. We cannot predict the consequences of the global warming which must eventually accompany this gigantic perturbation to the life support system of our planet, nor prescribe effective measures to address them, without a vastly improved understanding of the climate system, the oceans, and the living processes governing the planetary biogeochemical cycles of carbon and other nutrient elements. We must adopt a global outlook on environmental, economic and social processes to address global change effectively. One place to start is with the studies of the ocean-climate system I have described.

The main body of this Addendum is a manuscript entitled "Glacial-Interglacial CO₂ Change: The Iron Hypothesis," by Professor John H. Martin, Moss Landing Marine Laboratory, Moss Landing California. In it Prof. Martin describes how present-day and past oceanic primary productivity is limited not by nitrogen and phosphorus as is usually assumed, but by iron, also an essential nutrient for living things. He shows how in the past, warm interglacial periods characterized by high levels of atmospheric CO₂ were also periods of low iron supply to the open sea. Conversely, during glacial periods when atmospheric CO₂ was low, there was a fifty (50)-fold greater supply of iron to the oceans, in the form of windblown dust from land. He states that atmospheric CO₂ levels, and glacial-interglacial climate changes were caused by changes in oceanic primary production fueled by terrestrial iron inputs.

One exciting implication of this hypothesis is that a relatively small input of iron can stimulate very large increases in primary productivity. For example, the contents of one large iron ore carrier could carry enough iron to fertilize the Southern Ocean sufficiently to counteract the current annual rise in atmospheric CO₂ (Figure 1).

This idea represents one of the most scientifically conceivable, economically feasible ways for us to reduce the atmospheric CO₂ level. By contrast, reforestation of a land area the size of Australia would have no detectable impact; nor would massive conventional fertilization of the coastal zone worldwide.

Further research into the iron hypothesis and other mechanisms supporting increased oceanic primary production, in the form of JGOFS-type process studies and surveys, are a high priority for a US Global Change Program.

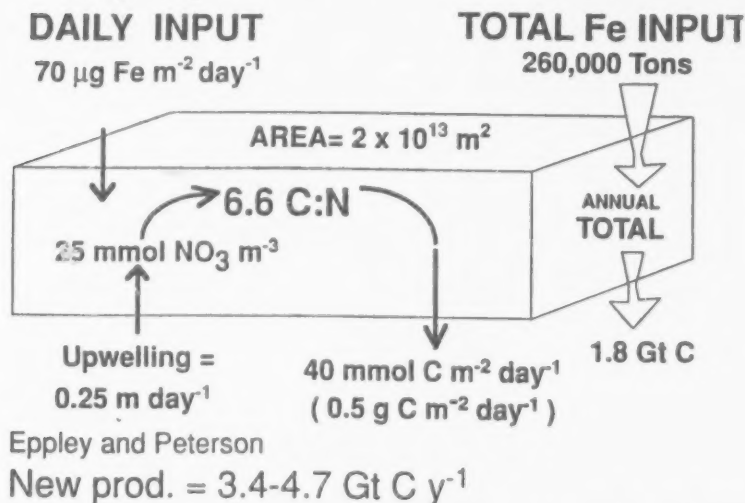


Figure 1. Diagram illustrating calculations to show how enrichment of the Southern Ocean around Antarctica with 250,000 tons of Iron (Fe) could stimulate a carbon removal of 1.8 giga tons per year. This is about the amount of the current atmospheric CO₂ increase.

Senator KERRY. Thank you very much.

I find that also very interesting and helpful.

Dr. Bretherton, you have been cited and referred to, and had your name taken in vain. Now you will have your opportunity.

STATEMENT OF FRANCIS P. BRETHERTON, DIRECTOR, SPACE SCIENCE AND ENGINEERING CENTER, UNIVERSITY OF WISCONSIN, MADISON, WI

Dr. BRETHERTON. Well, I am a scientist. My name is Francis Bretherton, of the University of Wisconsin, Madison.

I am a scientist, but I am here today not to talk about the science of global change, but, rather, to talk about the role of NOAA. Specifically, I am here as a member of the NOAA panel, advising NOAA on the climate and global change program within NOAA.

We have a report here, "The Vision: A Rededication of NOAA," which I believe you have seen. I would like that ² and my prepared written remarks to be a part of the record.

Senator KERRY. They will be.

Dr. BRETHERTON. I would like to start by picking up some of the things that we heard earlier this afternoon, in particular, the Assistant Secretary for Oceans and Atmosphere read some remarks of President Nixon, as part of NOAA's charter:

The oceans and the atmosphere are interacting parts of the total environmental system upon which we depend not only for the quality of our lives, but for life itself.

Establishment of the National Oceanic and Atmospheric Administration, within the Department of Commerce, would enable us to approach these tasks in a coordinated way.

I believe those statements are as true now and even more urgent than they were 19 years ago, when NOAA was created.

However, I would urge very strongly that they be implemented in full, particularly as regards to the global environment. That is the basic message that I wish to get across today.

The rationale for this, as we know, is, it is broader than just greenhouse warming and climate change. As you, yourself, Senator, are well aware, pressures on our environmental system are growing daily, both at the local, the regional, and the global level. Greenhouse warming, the ozone hole, tropical deforestation, soil erosion, estuarine pollution—all are symptoms of the human impacts on the system. These are impacts that we must face up to and learn how to contain to a tolerable level.

We, as scientists, know that all these symptoms are, in fact, interconnected. But we really are pitifully ignorant of just how the system functions.

Now, remember, when we have problems with our automobile, we take it to a mechanic, or at least we read the manual. For the global environment, there are no mechanics. There is no manual.

A fundamental challenge for the next decades is to obtain the knowledge with which we can write that manual and train the mechanics, so that our children and grandchildren will be better able to face what we leave behind us.

² The report was not reproducible.

This is not a luxury. It is a fundamental investment in the future of our human societies.

Now, facing this challenge will require cooperative efforts among many agencies and among many nations. But, any way you look at it, central to what has to be done are the responsibilities and capabilities of NOAA, which is the operational custodian of the state of the atmospheres and the oceans.

But I do not think that NOAA is in any shape, really, to live up to this challenge. The present levels of activity in this area, both in research and basic measurement, are clearly totally inadequate.

From the outside, quite frankly, I see an agency under siege. There are many fine, dedicated individuals in NOAA. But I also see that they are demoralized and frustrated by continual battles to preserve a budget, as Dr. Wallace referred to earlier, and also by battles to retain scientific standards and quality where they are continually under pressure from the lowest bid.

What we need is a far cry, I believe, from what we actually have at this moment. We have the nucleus to face up to that challenge; but it is going to take major steps to get there.

What are those steps?

First, you, Congress, have to exercise leadership. You have to require unequivocally that climate and global change be at least as high a priority as storm warnings and weather predictions.

You must back that statement up, both by oversight and by substantial incremental funding for the agency as a whole.

I have to disagree with the Assistant Secretary that the Fiscal Year 1990 request is adequate. It is clearly just the tip of the iceberg for what needs to be done, both in the focussed program and in the infrastructure within NOAA.

Second, the agency itself has to be restructured so that the reporting lines within the agency reflect these changed priorities. At this moment, you see that issues of climate and global change are always second priority in most of the operational lines of the agency, because that is the way the priorities are currently perceived to be.

Third, there are many individual changes in NOAA's programs that are going to be essential. I can only give you a personal view because I am not, I think, smart enough to talk on behalf of the whole community here. But my personal view of some of these changes is, firstly, we somehow have to insure that NOAA participates in the Earth Observing System program, which is currently being proposed by NASA and, until last year, NOAA was an equal partner in that.

For various reasons, it has been necessary to take NOAA instruments off the polar platforms spacecraft themselves. It is absolutely essential that, in terms of data management and integrated functioning, NOAA stay an integral part of that program and in a position so that, as the research instruments put out by NASA mature and are proven, NOAA can take over their operations as a going concern.

Secondly, NOAA has to develop outreach on the system modeling, built around the first-rate capabilities in the Geophysical Fluid Dynamics Laboratory on the atmospheric climate system, and, to some extent, the physical circulation in the ocean. NOAA has to

consciously build expertise and coordination with what is going on in the universities and other agencies, particularly in the chemical parts of the system and the biology.

Thirdly, it is essential to put adequate calibrations on the weather satellites, so that some of these other variables, like cloudiness, which are potential products out of the weather satellites at this time, in fact can be reliable over long-term changes, such as we have to document in global change.

Fourth, the LANDSAT program is critical, both because of the Sea-WIFS instrument that you have just heard about, but also because of the store of data that is there to estimate the changes that human activities are making on land cover, an absolutely fundamental variable for understanding what is happening on the land surface.

Fifth, in the data system, we have to insure that the data centers are staffed with scientists who are really able to interface with the scientific community on the global change research needs.

At this moment, some of the NOAA data centers have some scientists on their staff; others have virtually none. And the effectiveness of those centers as a focus for the research and for effective exchange with the scientific community is directly proportional to the number of scientists on the staff of those data centers.

We have indeed to expand substantially and put on an on-going operational basis NOAA's measurement programs in ocean circulation and ocean CO₂, that we have already heard about.

We have to reanalyze existing climate data records, such as surface temperature. One of the basic response variables, the global temperature of the world to the increase of fossil fuel burning and carbon dioxide in the atmosphere, that basic response variable is in serious doubt. We have 100 years of measurements and 100 million observations; and we are not, in fact, able to determine unequivocally whether the world's temperature is going up or not, or how fast. This is not because of lack of measurement, but because of the way the data was processed and the way the records have been kept.

We have to, first of all, put our existing records in the best shape we can. Then we have to be absolutely certain that we do not repeat those mistakes for the future.

At this moment, I see no signs whatsoever that our track record for the next 50 years will be better than our track record for the past 50.

We, finally, in specific terms, have to support strongly the NOAA program in radiatively important species and some of the other gasses, besides carbon dioxide, such as methane, which are also important in understanding what is happening to the global environment.

But perhaps most important of all, we have to insure that the message gets across to the staff of NOAA that this is a scientific agency with the highest standards of scientific and operational achievement, which really can be a source of pride and leadership within the world community about how really these environmental issues have to be addressed.

To conclude, I would just like to borrow a little phrase from a colleague of mine, Professor Suomi, at the University of Wisconsin.

In the early 1970s, it was the Environmental Sciences Service Administration—"yes suh." It then became the National Oceanic and Atmospheric Administration—"no-uh." What we have to do is to put "global" into the title, and make it "go-uh, go-uh."

Thank you.

[The statement follows:]

Senate Committee on
Commerce, Science, and Transportation
and the
National Ocean Policy Study

A statement by

Francis P. Bretherton
University of Wisconsin - Madison

April 11, 1989

I am here on behalf of an external NOAA Panel on Climate and Global Change. This statement should be read in conjunction with a report of that Panel:

"The Vision: A Rededication of NOAA", obtainable from:
Office of Interdisciplinary Earth Studies
University Corporation for Atmospheric Research
PO Box 3000
Boulder, CO 80307

I will start with a quotation:

The oceans and the atmosphere are interacting parts of the total environmental system upon which we depend not only for the quality of our lives, but for life itself.

We face immediate and compelling needs for better protection of life and property from natural hazards, and for a better understanding of the total environment -- an understanding which will enable us more effectively to monitor and predict its actions, and ultimately, perhaps to exercise some degree of control over them.

Establishment of the National Oceanic and Atmospheric Administration (NOAA) -- within the Department of Commerce would enable us to approach these tasks in a coordinated way.

Richard Nixon
The White House
July 9, 1970

This vision is as valid today as when NOAA was established 19 years ago. I am before you now simply to urge that it be implemented, in particular, in relation to a better understanding of the total environment.

Recent international meetings have made it clear that issues of the global environment have moved high on the agenda of many countries of the world. The greenhouse warming and the ozone layer are both currently subjects of international assessments and policy discussions. Acid rain, the loss of productive land to deserts, the destruction of tropical forests and the associated extinction of millions of species, are additional symptoms of the growing influence of human activities on the functioning of this planet. Scientists know that these are all interconnected aspects of the Earth system, though the details of those connections are still very unclear. Our present understanding of this system is but fragmentary and clearly inadequate to the needs of policy makers making decisions involving trillions of dollars. For example, there is consensus about trends in global climate, but there are no reliable predictions of regional changes or other impacts. As pointed out by World Commission on Environment and Development in its report "Our Common Future", a sustainable environment is essential for the support and economic development of world population, yet is also threatened by them.

The President recently forwarded to Congress along with his FY90 budget a report "Our Changing Planet: A U.S. Strategy for Global Change Research", prepared by the Committee on Earth Sciences of the Federal Coordinating Council on Science, Engineering and Technology. This represents the first step in a proposed inter-agency program that builds upon and broadens activities already underway within the National Climate Program. The scientific requirements have been outlined in reports of the National Research Council, such as "Toward an Understanding of Global Change", and by the NASA Earth System Sciences Committee. We are on the threshold of a national commitment to a long term program to build the basis of knowledge and understanding that our children and grandchildren will absolutely require to cope with the world that we leave behind us. The effort and resources required will be substantial, but this commitment is an investment that we cannot afford not to make.

Implementing such a program is a tremendous challenge, and no one agency can undertake it alone. Within established agency roles, it requires a mechanism to establish a focus, and to ensure that the focus is maintained. It requires documenting the changes that are occurring on a global scale over the coming decades, understanding the processes that are giving rise to them, predicting the outcomes of existing trends and possible alternative actions, and making information available to a broad community of researchers and decision makers both now and in the future. It involves observations of the atmosphere and ocean, of the land surface, soils and biological communities, of the records contained in ice sheets and deep sea sediments. It requires ships, aircraft, satellites and fixed measurement stations, and the development of new techniques of measurement. It involves both basic research and into processes and long term monitoring. It requires data systems and communication networks. It involves synthesizing in computer models detailed information from many different scientific disciplines and agency

responsibilities. It requires a team of people dedicated to patient interpretation of the available facts, and to fitting each new fragment of the jigsaw into a coherent whole on an ongoing basis. It requires original thinkers who will test that emerging picture in new ways, and skeptics who will question its foundations. To achieve this goal new priorities must be assigned, institutional structures must be redesigned, new resources must be made available, new people must be entrained, and new modes of cooperation must be established -- among agencies, between agencies and universities, and between agencies and their counterparts in other nations.

The National Oceanic and Atmospheric Administration must play a central role in this program. NOAA is the logical candidate to ensure the synthesis of climate and global change measurements and information on an operational basis into a coherent picture suitable for prediction and impact assessment, complementing other U.S. agencies in their essential roles in the national program. No other agency has existing responsibilities for ongoing measurements, data management and synthesis, prediction, and supporting research, across such a broad spectrum of the scientific areas involved. The existing capabilities for weather prediction and oceanic measurements, for climate and fisheries research, together with the NOAA data centers, form an essential nucleus around which this role could be built. These capabilities would have to be enhanced and restructured to support new responsibilities and priorities. Major new resources would have to be made available. The present budget for Climate and Global Change would have to be expanded by at least a factor of ten, in addition to strengthening the common infrastructure of measurement systems and supporting facilities on which both it and other present NOAA activities depend. The organization would have to be restructured to reflect a priority on Climate and Global Change at least equal to that accorded these other activities. New approaches would be required to involve the skills in universities and other agencies, particularly in relation to measurement systems development, global change processes, and the whole area of ecosystems and global biology. Above all, an atmosphere has to be created in which talented scientists and managers see a real opportunity within the agency to serve their country and humankind, by setting standards of excellence and achievement on one of the most challenging problems facing our society today.

This vision requires the rededication of NOAA to the purposes so eloquently expressed in its original charter. If we let it pass by, a new organization will have to be created to achieve the same purpose, but without the synergism that could both build upon and enrich NOAA's present emphases on weather prediction and coastal zone management. We owe it to the nation and to our descendants to meet this challenge.

Senator KERRY. Thank you very much, Doctor, for not only articulate, but I think very important testimony. I am delighted that you were very direct and candid in sharing with us your perceptions, which I think a lot of people feel. But it is sometimes hard to get it on the record as directly as you have been willing to give it.

You talked a moment ago—and we are a little pressured on time today, so I am going to have to wind up terminating probably before I have exhausted even half the questions that I have. But I am going to submit some in writing for each of you, if you would bear with me on that score.

Doctor, the data collection process—you have talked about the LANDSAT importance and I agree, and those schedules trouble me. In fact, I meant to ask and one of the questions I will be submitting to the administration is what is their current schedule for the production of those launches and so forth.

But, query, whether or not when you take the NOAA three data centers, you have NASA and the various other agency data centers that are coming in, and that is just the United States. Then you have other countries gathering data and so forth.

How available is all this information to researchers?

Dr. BRETHERTON. Some of it is fairly readily accessible. A lot of it, particularly the satellite data, because it is so voluminous, is so hard to get at and so expensive to get at that, in fact, it might as well not exist.

Senator KERRY. Is there a system that could more officially handle that and make it available for the study of global change?

Dr. BRETHERTON. I have been participating for the last two years with Mr. Pyke, who was sitting in this chair in the previous panel, with Dr. Tilford from NASA, and with a number of people from other agencies in discussions about what really the inter-agency data system should be for the year 2000 or so for global change purposes.

Senator KERRY. What is the appropriate NOAA role in that?

Dr. BRETHERTON. It is very central as one of the major archival activities, as one of the agencies that has an ongoing operational responsibility to take the existing sources of data and turn them into useful products, to global analyses, which have a long-term validity that stands up to what I call the 20 year test—that is, what will our successors think 20 years from now when they are measuring the same variables as we are and are trying to figure out whether the changes they observe are real or artifacts of the way we took or handled the data.

Now, NOAA has a major role in that integration and synthesis process.

Senator KERRY. Going beyond that synthesis process, I would like, for the record, to have you give me your assessment of how vital NOAA is to the success or failure of global change research.

Dr. BRETHERTON. It is absolutely essential. It has a key role in two other areas—in the actual modeling, the development of large-scale models of the climate system, where I think the world leaders are, in fact, in NOAA's Geophysical Fluid Dynamics Laboratory at this time.

It also has a key role in mission directed research, which is focused on building the measurement capability and understanding

enough about the processes so that they can be effectively integrated into the large-scale models.

NOAA has a central role built around its capabilities in the atmosphere and the ocean in all the major areas of global change research.

Senator KERRY. My final question is what would you identify as the highest priorities for NOAA in terms of the global change research program?

Dr. BRETHERTON. Money.

Senator KERRY. It's called a "soft ball," isn't it? It is now baseball season. We opened yesterday, and the Red Sox won. Incredible. Somebody cheered, right.

Dr. Ducklow, if I could ask you this, I have had a long-time interest in acid rain and have been very involved in that issue for a long period of time.

Last year, we had a hearing here on the effects of acid rain on marine environment. Witnesses testified that acid rain, as I mentioned in my opening comment, could lead to an increased growth of phytoplankton.

You have suggested, I think, or it has been suggested that phytoplankton may reduce the greenhouse effect, because they pump carbon dioxide into the deep ocean. Is that correct?

Dr. DUCKLOW. Yes.

Senator KERRY. Therefore, is there any way, or can one draw a conclusion or try to create a link that somehow acid rain could mitigate global warming?

Dr. DUCKLOW. Senator, I think the mechanisms by which that might happen are not well understood. However, one can do the calculations and, even if we decided to discount the other social costs of increased acid rain, the total increment in global primary production that that might stimulate is a drop in the bucket, compared to the CO₂ decrease that we require.

You can add to that the already undesirable nutrient enrichment of the coastal zone by sewage and so on, which similarly is just not a very important factor on the global scale.

Senator KERRY. You talked about the Sea-WIFS. I wonder if you could state just for the record why that satellite instrument is so critical to research.

Dr. DUCKLOW. It is critical for two reasons. One is that it is our only means of having a day-to-day, global-scale look at the biological pulse of oceans in the global carbon cycle. Secondly, beyond the monitoring of the biological activity of the ocean from space itself, it provides us with an unsurpassed tool, an unequalled tool, for guiding our work on ships and with other kinds of instrumentation, so that we can provide the larger scale context for the kinds of mechanistic studies that we do.

Without one right now, we are sort of working blindly.

Senator KERRY. And the current status is what?

Dr. DUCKLOW. The current status is that the satellite is very much in jeopardy as a result of the breakdown in negotiations between NASA and the EOSAT Corporation and the general uncertainty with the LANDSAT program.

Senator KERRY. This is for any one of the four of you. Other nations are also involved in some research with respect to these mat-

ters. Are we doing enough, and have we created a process by which we are doing enough in terms of international cooperative effort in this field.

Dr. BRETHERTON. I can take that one.

The programs that we are talking about here are built upon the world climate program that was instituted some ten years ago, and the national part of that.

The planning process for the physical part of the climate system, the physical atmosphere in oceans, is fairly well underway. There are projects, like the World Ocean Circulation Experiment, indeed, the Tropical Oceans Global Atmosphere Program that Professor Wallace talked about, which are integral parts of that international planning exercise.

What is relatively new is the realization that we also have to incorporate in our view of this system the biology and the chemistry, that we have, in fact, to take a much broader view of the system that we are talking about.

For this purpose, the International Geosphere-Biosphere Program, or IGBP, is currently being planned. The U.S. has taken a leadership role in getting both these sets of activities going.

There is very strong participation, both from European nations, Japan, and a lot of interest in the Soviet Union, in China, in a lot of different countries in the world.

Always on an international level progress seems painfully slow, simply because there are so many people who have to be brought up to speed on what the basic issues are and what the common approaches are.

I, frankly, am impressed by what is being done. I think the U.S. has probably done as much as it reasonably could have done to this date. I am also frustrated that things are not moving faster.

Senator KERRY. Peter, the Oceanographic Fleet of NOAA I gather is being diminished, rather than augmented. I understand that they are taking out six ships—is that accurate—or are planning to? Is that correct, that they are going to lay up six ships?

Dr. BREWER. That is the account that I have read, yes.

Senator KERRY. What would the impact of that be?

Dr. BREWER. I personally have never sailed on a NOAA ship. But, looking at the state of the U.S. fleet and the needs, we are going to have four vessels to observe the ocean. It must be very bad indeed.

Senator KERRY. Do you have any way to assess what the general condition of the U.S. Oceanographic Fleet is?

Dr. BREWER. Yes, I do, both from personal experience and planning.

Senator KERRY. How would you assess it?

Dr. BREWER. As not very good. Our ships are old. Two of our major academic vessels are now in the process of being refurbished. This is a mid-life step. So we will get half a lifetime of good ships out of them.

The NOAA ships are not run on the same standards as academic ones. They are staffed by uniformed officer corps, so there are structural problems for academic scientists working on them. But we are going to need those vessels if we are going to cover the world and make measurements, as I believe we should.

Senator KERRY. Is it fair to say that laying up six ships would have an impact on the global research project?

Dr. BREWER. Yes, it is fair, Senator.

If I could make one request, just getting one NOAA Class I research vessel, dedicated, say, as a global change research ship, will be a great asset.

Senator KERRY. Unfortunately, the quality of this panel dictates that I should really stay here and ask a lot more questions, and I would like to; but the quality of life in the Senate dictates that I have to move on, unfortunately, to something else. I apologize for that.

But I do want to leave the record open. As I said, there may be some additional questions for the record. I think this record is a very important one.

I want to thank you because it is clear to everybody that we have a long, long distance to go in a very short span of time. Having been very much involved in the Plastic Pollution Treaty effort that we passed last year, but recognizing the difficulties of enforcing it, and being more than familiar with the problems of the Boston Harbor and raw sewage being dumped, as well as the other things that we have talked about, it is clear that we are proceeding down a road where we simply do not know the consequences of our own actions.

I cannot think of anything more frightening than that, considering the fragility of the resources that we are dealing with.

You were talking earlier about mechanics and manuals. I sort of instantaneously thought about the early days of the automobile. Obviously, some quick experts developed and people who were driving cars knew how to fix their own car pretty well. They became the people who wrote the manuals.

I suspect that is pretty much where we are with a lot of these environmental issues, that people have a pretty good sense of what is needed. But we sure ought to get the manual written pretty quickly.

I am going to do everything that I can, and I know Senator Hollings is committed to doing everything that he can, and already is working on the \$20 million issue. But, clearly, we have to go beyond that. I think you will have significant cooperation from the Committee in the effort to try to guarantee that we define a clear process here and move forward as expeditiously as possible.

I want to thank you for your contributions to this dialogue and for your patience in the course of today.

This hearing will stand adjourned.

[Whereupon, at 4:05 p.m., the Committee adjourned, to reconvene upon the call of the Chair.]